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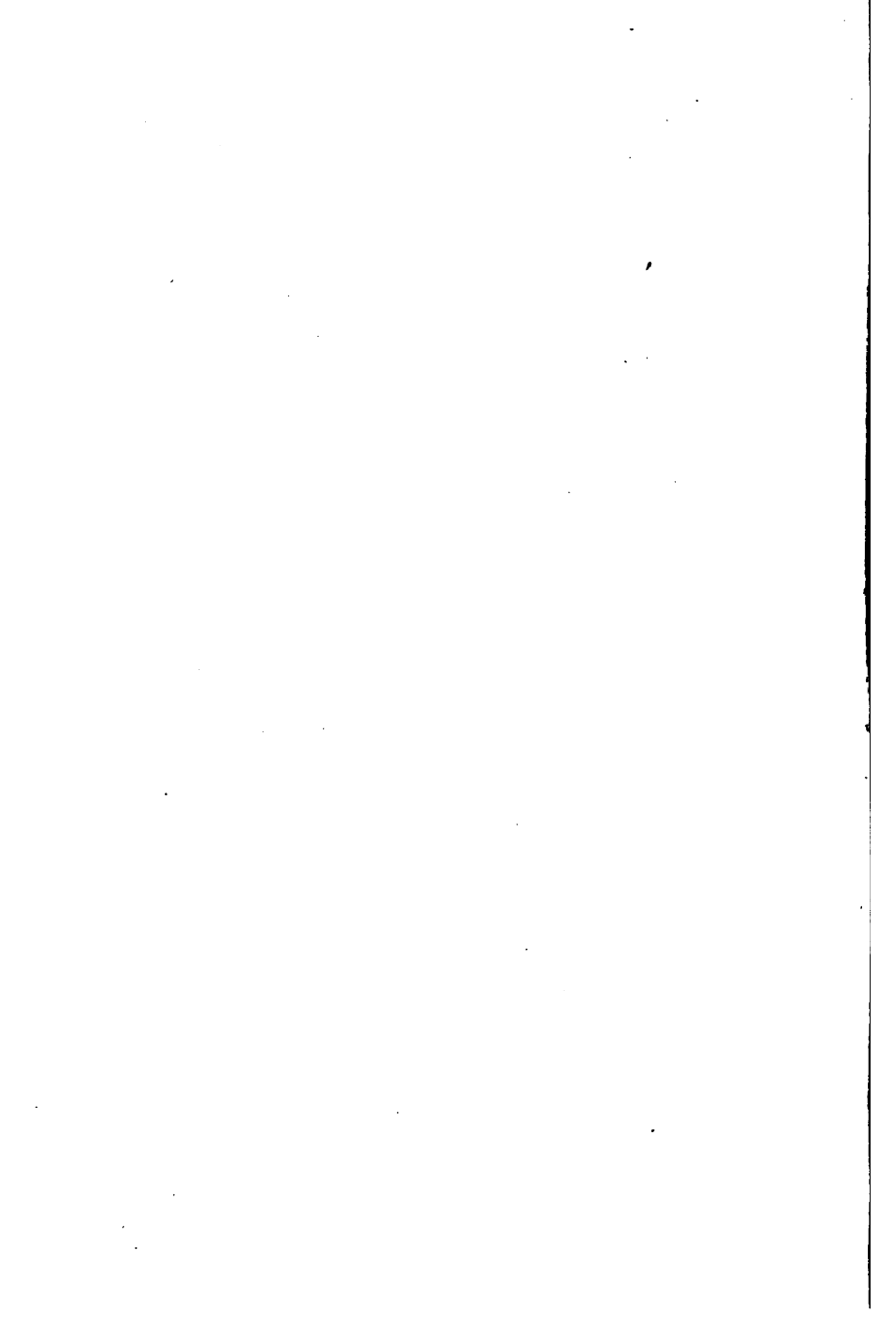
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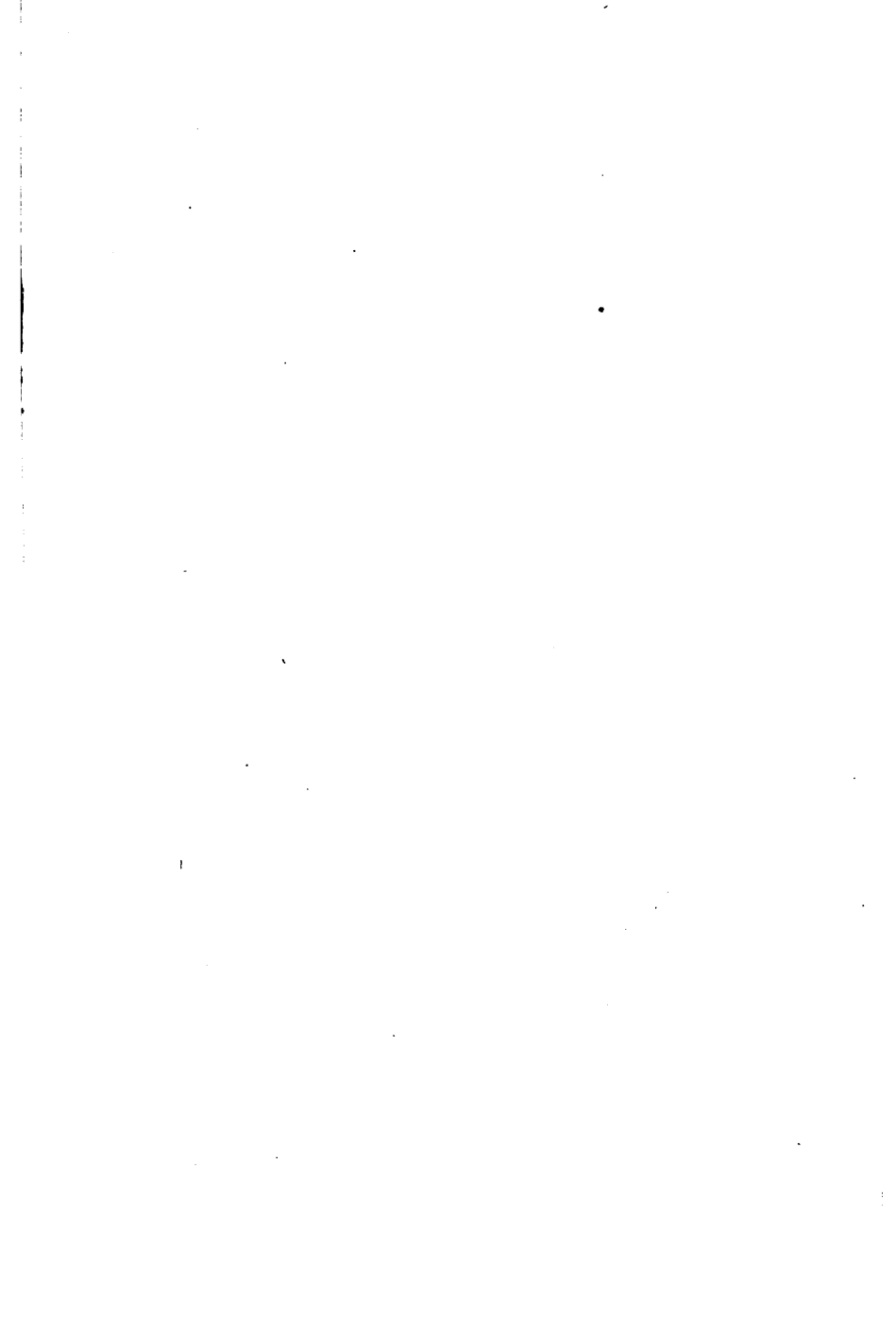
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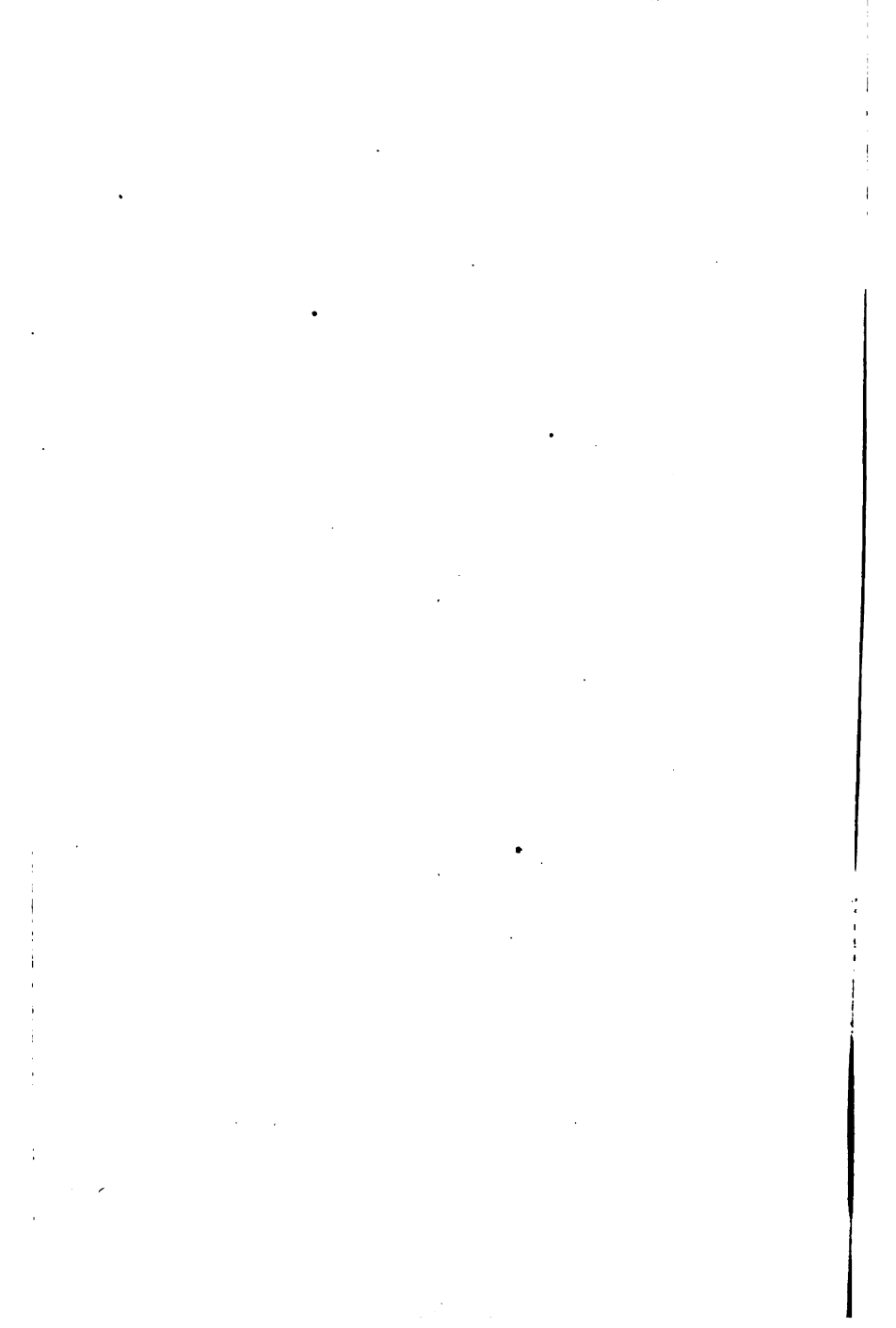
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GENERAL AGRICULTURAL CHEMISTRY

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PREFACE

Since the time of Liebig, agriculture in its many phases has profited from the science of chemistry. A store of useful information has been made available through the study of the elements and compounds fundamentally concerned in the art of agriculture. It is reasonable to expect that this art will in the future be enriched from the same source.

This little book was written in the interest of the young farmer and the student beginning the study of agricultural chemistry. No extended knowledge of chemistry is required for its understanding. It makes no special appeal to the chemist. It is a survey of the general field of chemistry applied to agriculture, with the emphasis always placed on the applied side.

Throughout the book we have striven to express safe views rather than to echo the most recent. Hypotheses and theories have not been discussed. We have attempted to give, in general, only well tested and established principles. Formulas and recipes have been avoided as far as possible. While we recognize their helpfulness, nevertheless, they are as yet but imperfect expressions of relations not fully understood.

The authors have drawn freely from various publications, endeavoring to bring together from scattered sources the materials essential to such a work on agricultural chemistry. In this regard we are especially indebted to the works of Ingle, Warington, Storer, Voorhees, Vivian, Jordan and others, all of which have aided greatly in the preparation of this work.



CHAPTER I.

INTRODUCTION

Agricultural chemistry concerns itself with the chemical composition of the food of plants and animals and with the chemical changes involved in the processes of life. It has to deal with the composition of soil, air, and water, of the bodies of plants and animals, of manures and commercial fertilizers and with the chemical changes which these substances undergo.

Before beginning the study of the soil or air or the plant it will be necessary for the student to learn something of the important elements concerned in agriculture and the meaning of some of the common terms used in chemistry.

The whole earth, so far as is known, is made up of about eighty-one elements, a large proportion of which play little or no part in the ordinary processes of plant and animal life. Indeed a considerable proportion are found only in extremely small quantities and are but curiosities to the student of chemistry. From the standpoint of the farmer they possess no interest. They are called elements for the reason that they are the simplest substances known, and cannot by any means yet discovered, be separated into simpler or different substances. Iron, gold, silver, zinc, lead, and sulphur are examples of elements.

The bodies of plants and animals are built up of compounds of the following elements and these, therefore, become of the first importance to the farmer :

Oxygen	Phosphorus	Sodium
Hydrogen	Calcium	Iron
Carbon	Magnesium	Chlorine
Nitrogen	Potassium	Silicon
Sulphur		

A short account of these elements will be given at this place.

Oxygen (O) is the most abundant and most important of the elements. It forms about half the weight of the solid crust of

the earth, eight-ninths of the water, and about one-fifth of the weight of the air. In the first and second instances the oxygen is in a combined state. That which is held in chemical combination in the soil takes no part in the formation of plant tissue. In the atmosphere it exists as a free element, merely mixed with the other constituents. Oxygen in the interstices of the soil is an active agent in bringing about many chemical changes, as oxidation of the organic matter and disintegration of the soil particles. It also forms about fifty per cent of the compounds found in plants and animals.

Oxygen is a colorless, odorless gas and very slightly soluble in water. It shows great tendency to combine with other substances and the act of union is usually attended by the production of much heat. Burning or combustion is nearly always due to the heat produced by the combination of the substance burned with the oxygen of the air. Any substance, which will burn in air (containing about twenty-one per cent of free oxygen) will burn with increased brilliancy in pure oxygen.

It is possible, with suitable apparatus, to measure the quantity of heat a substance will produce when burned. The unit of heat here employed is the "calorie," which represents the quantity of heat required to raise one gram (about 1-28 of an ounce) of water from 0° to 1° on the scale of the centigrade thermometer. A large Calorie, one thousand times larger than the above, is employed for the expression of large quantities of heat and will be employed here.

When one gram of the following dry substances is burned in oxygen, the quantity of heat produced, expressed in large Calories, is as follows:

Charcoal	8.0	Fat of sheep	9.4
Hydrogen	34.4	Fat of butter	9.2
Wood	2.8	Cane sugar	4.0
Coal	7.5	Cellulose	4.1
Coke	7.0	Starch	4.1
Casein	5.8		

In ordinary cases of burning, the evolution of heat is readily evident, but in some cases the combustion is so slow that the heat evolved is carried away as fast as produced and very slight or no elevation of temperature is apparent. In some cases of slow combustion where the escape of heat is hindered from any cause, the temperature may rise so as to be perceptible or even dangerous. It may, under particularly favorable conditions, rise sufficiently to start a rapid combustion with oxygen and flames then result. Such cases of "spontaneous combustion" frequently occur. Drying oils, as linseed or cotton-seed oil, especially when spread on cotton waste, and fermentation changes in vegetable matter as hay and tobacco are notable examples of these conditions.

Hydrogen (H). This element is rarely found in a free state in nature, but is combined with carbon and oxygen as in animal and vegetable matter, with oxygen to form water, and in a few cases with some of the base elements to form hydroxides. It is not found in large amounts in the soil and that which forms a part of the tissues of plants and animals comes largely from the hydrogen in water. It is a colorless, odorless gas and characterized by its lightness. This fact has led to its use for filling balloons, although coal gas is now more generally employed but is not nearly so efficient. In a free state it has been found in the gases escaping from volcanoes.

Carbon (C) is the element most closely associated with plant and animal life. It forms a large proportion of the solid matter of all living beings; and the chemical processes of animal and plant life are mainly those in which carbon plays an important part. It exists in the combined state in many minerals as the carbonates of calcium, magnesium, iron, zinc, and also in a small but very important constituent of the air, carbon dioxide. The carbon of the soil, where it exists as the main constituent of organic bodies, takes no direct part in forming the carbon compounds of the plant. It is not necessary to apply carbon fer-

tilizers to produce the carbon compounds of the plant, because the carbon dioxide of the air is the source for crop production. It is estimated that there are about thirty tons of carbon dioxide in the air over every acre of the earth's surface.

This element occurs in three distinct forms: (1) as the diamond, (2) as graphite and (3) as charcoal, lamp black, etc. The diamond is crystalline and transparent; graphite is crystalline but opaque; while lamp black and charcoal are non-crystalline. The black carbon which is produced when animal or vegetable substances are strongly heated without access of air (char-ring) is due to the separation of free carbon from the various carbonaceous compounds present.

Nitrogen (N) is much less abundant in nature than the elements already described. A peculiarity of its occurrence is that it appears to be present only in the outermost portion of the earth, the greater portion being free in the air. No true minerals containing it are known except those which owe their origin directly to plant or animal life, as coal, and Chili salt-petre. All living matter, however, contains it as an essential constituent. In its free state it is a colorless, odorless gas, showing little tendency to combine with other elements. It constitutes about seventy-nine per cent of the atmosphere and over each acre of land there is consequently about thirty thousand tons.

Although in the free state it is so inert, the nitrogen compounds, as a rule, possess great chemical activity and many are very important substances. Some powerful drugs and poisons as quinine, strychnine, and prussic acid contain nitrogen, while most explosives, as nitro-glycerine and gun cotton are also nitrogen compounds. It is an absolutely essential ingredient in the food of both animals and plants. It must be supplied to animals in compounds in which it is combined with carbon, hydrogen, oxygen, and certain other elements and which are known as proteins. While plants acquire it generally from nitrates, which are simple compounds of oxygen, nitrogen, and some base, as calcium, sodium, and potassium. Only under very special conditions can

some species of plants obtain their necessary nitrogen from the air. It will be seen in the later chapters that, although plants are surrounded by air, rich in free nitrogen, combined nitrogen is one of the essential and most valuable constituents of manures. A large part of the nitrogen in the food consumed by man and animals is eliminated as simple compounds in the excreta and unfortunately, especially in our cities, sent down the sewers and rivers and finally discharged into the sea. To agriculture this valuable combined nitrogen is therefore wasted. This element is the most expensive of those necessary for plant growth and is among those liable to be most deficient in our soils. No other element takes such an important part in agriculture or in life processes.

Sulphur (S) is found both free and combined in nature. The free element is found in volcanic districts, while in the combined state it occurs as hydrogen sulphide in mineral waters and as sulphides of many metals, as for example iron, lead, and zinc. The sulphide of iron, known as iron pyrites, is often mistaken for gold because of its yellow color; sulphur also occurs as sulphate of calcium, in which form it is very widely distributed in soils, and is the main source of the sulphur for crops.

The element sulphur (brimstone) is a yellow, brittle substance and very inflammable. It burns in air with a pale blue flame, forming the suffocating gas, sulphur dioxide. Such forms of sulphur are very poisonous to plants and animals, while sulphates are not only harmless, but necessary. Sulphur is present in the proteins of both plants and animals and when putrefaction of these substances occurs is often liberated as hydrogen sulphide. This substance is perceptible by its disagreeable odor as one of the chief products of the decay of eggs.

There is generally less than 0.10 per cent of sulphur trioxide, as sulphates in ordinary soil, and it is now known that the amount required by crops is considerable; for this reason it may be necessary to use certain sulphates occasionally as fertilizers and as sources of sulphur for the growing crops.

Phosphorus (P) always occurs in a state of combination. Phosphorus compounds, chiefly phosphates, are very widely distributed, but in small proportion, in the rocks of the earth. Deposits of calcium phosphate occur in certain localities and are one of the chief sources of our phosphate fertilizers. All fertile soils contain small quantities of phosphates, which are taken up by plants and through plants find their way into animals, where they accumulate in the bones or other hard parts, as teeth and shells.

The element phosphorus, as usually prepared, is a yellowish waxy substance, which has the power of emitting a faint light when exposed to the air. This property was the origin of its name, which is derived from the Greek and means "the light bearer." The emission of light is due to slow combination with the oxygen of the air, resulting in the production of heat.

Phosphorus is a violent poison. It is largely used in the manufacture of lucifer matches and rat-poison. For the farmer its chief importance lies in the use of its compounds, the phosphates, as fertilizers, and its occurrence in certain fats and protein compounds of feeding stuffs and in the bodies of animals.

Soils are quite liable to be deficient in phosphates, as the latter are largely drawn upon by many crops, particularly grain crops, where the phosphorus accumulates in the seed and is sold from the farm.

Calcium (Ca) is very abundant in nature, always occurring in a combined state. Calcium carbonate is found in enormous quantities, as chalk, limestone and marble, and contains the three elements, calcium, carbon and oxygen. It also occurs as gypsum, a compound of calcium, sulphur and oxygen. The element itself is an easily oxidisable metal, difficult to prepare, and of no importance to the farmer. Its oxide, or a compound of calcium and oxygen, is the important substance, quick lime. This is made by burning limestone, whereby the carbon and part of the oxygen are removed as a gas. Calcium is an essential constituent of

plant food and in the soil is present in a variety of forms, as calcium carbonate, calcium sulphate and calcium phosphate.

Potassium (K) occurs in many minerals. It will be found in many silicates, as orthoclase or mica, which are complex compounds of potassium, silicon, aluminum, oxygen and other elements. It also occurs in sea water, from which sea weeds accumulate large quantities of potassium compounds. The immense salt deposits at Stassfurth, Germany, furnish a large proportion of the potassium used in our potash fertilizers.

The element is a lustrous metal, very soft, and so susceptible to change in the air that it must be kept away from contact with air or moisture by immersion in naphtha. By contact with water it reacts violently, producing much heat and floating on the surface of the water with a hissing sound.

Potassium compounds are of the greatest importance in agriculture and are necessary constituents of all fertile soils. They are intimately associated with the growth and increase of plants and are always found in greatest abundance in the twigs, young leaves and other rapidly growing portions. In some plants the potassium is in combination with certain organic acids, as citric and tartaric acids. In the ash of plants—that which is left after burning—it generally occurs as a carbonate. Potassium salts are very soluble in water, but are absorbed and retained by certain constituents of the soil, so that their loss by drainage from soil is little to be feared.

Sodium (Na) is very widely distributed in nature and is a constituent of many silicates. In the form of sodium chloride—a compound of sodium and chlorine—it is very plentiful as rock salt and as the largest saline constituent of sea-water.

Its properties resemble those of potassium. Sodium compounds are largely used in the arts and the preparation of sodium carbonate is one of the largest and most important of chemical industries.

Sodium is found in the ash of most plants, but, except in the

case of certain plants, does not appear to be essential to their development. A striking difference between sodium and potassium compounds, which are so much alike in most of their properties, is in their behavior towards the soil when applied in solution. The potassium salts are retained by the clay and organic matter in an insoluble form, but the sodium salts are more easily washed out by water and escape into the drains. Although like potassium in its chemical properties it cannot take its place in agriculture.

Magnesium (Mg) is widely met in nature as carbonate and silicate. The element itself is a bright, silvery metal, and capable of burning in air with an intense and dazzling white light. Magnesium is found in the ash of plants and is required by all crops. It is particularly abundant in the seeds. There is generally in all soils an amount sufficient for crop purposes and it is not necessary to consider this element in connection with fertilizers.

Iron (Fe) occurs in a large number of compounds. Haematite, a compound of iron and oxygen, magnetite, a similar compound, but with a different proportion of oxygen, and spathic iron ore, a compound of iron, carbon, and oxygen; the above are all abundant minerals and valued as ores of iron. The element occurs in two states of combination with oxygen, one a relatively small amount and called ferrous iron, the other a relatively larger amount and designated ferric iron. The former yields salts which are white or green in color, while those of the latter are red or yellow. Ferrous compounds are often present in rocks or minerals deep under ground, but when brought to the surface they combine with the oxygen of the air to form ferric compounds. The change of the state of iron is indicated by a change in color, often from green or gray to red or yellow. Only ferric compounds should exist in good soils. Iron is essential to plants, but a small quantity is all that is required and most soils contain from one to four per cent, an abundant supply.

Chlorine (Cl) is very abundant, especially in combination with sodium, as rock salt in the sea and in spring water. Other compounds of chlorine also occur as minerals. The element chlorine

is a yellowish green gas with an irritating and suffocating smell, very soluble in water and of great chemical activity. The properties of chlorine, which are most valued in the arts, are its bleaching, disinfecting and deodorizing powers. It readily destroys most coloring matters and is largely employed in bleaching vegetable textile fabrics, as cotton or linen. It cannot be used for woolen or silk fabrics, as it injures the fibres themselves. Chlorine only bleaches in the presence of water and it really acts by decomposing the water, with formation of oxygen, which is the active agent. Its action as a disinfectant is probably due to the same process, the oxygen of the water combining with the organic matter and micro-organisms and destroying them.

Chlorine is present in all soils, generally in combination with sodium, as sodium chloride. It is present in all plants, although its necessity for plant growth may be questioned. Crops have been brought to maturity in its entire absence. Chlorine with sodium, as common salt, is sometimes used as an indirect fertilizer.

Silicon (Si) is extremely abundant in the rocks of the earth's crust, and though it forms a very important ingredient in soils and occurs in most plant ashes, it does not appear to be absolutely essential as a plant food. Some recent work, however, has shown that soluble silica in a soil enables a plant to subsist in the presence of a smaller quantity of phosphoric acid than would be necessary without the silica.

The element itself is a brown solid and at one time was difficult to prepare in any quantity. At present, with the electric furnace, it is easily produced and its price per pound has been greatly reduced.

The oxide, called silica, is a compound of silicon and oxygen and is a very abundant substance, occurring free as quartz, flint and sand; in combination with metals the very numerous and important substances called silicates, are produced. It has been estimated that nearly half of the solid mass of the earth's crust consists of silica.

DEFINITIONS.

It now becomes necessary to define, in a fragmentary way, some of the commoner terms used in chemistry.

Acid. A substance generally possessing a sour taste and the property of changing vegetable blues, as blue litmus, to red. As types of acids, we have sulphuric acid, commonly used for the Babcock test, and acetic acid, the principal acid in vinegar. The possession of a sour taste and the power of changing vegetable blues to red is indicated by saying that the substance has an acid reaction.

Alkali. A substance opposed in its properties to an acid, capable of neutralizing and destroying the characteristics of an acid, forming in so doing, a salt. The most important alkalies are soda, potash, lime, and ammonia. A substance is said to have an alkaline reaction if it turns certain vegetable colors, as red litmus, to a blue color.

Organic matter, strictly speaking, is matter which has been produced by organisms, such as plants or animals, but the term is used in a wider sense in chemistry for any compound of carbon, whether produced by life processes or artificially. Almost all forms of organic matter, when strongly heated out of contact with air, blacken, owing to the liberation of carbon. With free access of air, combustion occurs, and carbon dioxide and other products are formed.

Oxidation and Reduction. By oxidation, literally speaking, is meant union with oxygen, but in a chemical sense the term is given a wider significance, that is, combination with more oxygen or with some substance playing the part of oxygen.

Reduction is used in exactly the opposite sense. A substance which brings about oxidation, is called an "oxidizing agent" while one which removes oxygen is called a "reducing agent." Common oxidizing agents are air, nitric acid, nitrates and chlorine; common reducing agents are easily oxidizable metals, as zinc, and many forms of decaying organic matter.

Fermentation. A process of decomposition, often accompanied by the oxidation of carbonaceous matter, and produced by the life processes of bacteria, yeasts and molds. When the process occurs out of free access of air and bad smelling gases are formed, the process is called *putrefaction*.

The constituents of plants. All agriculture depends upon the growth of plants and consequently all profit for the farmer depends upon the value of the crop his farm produces. This is true whether the crop is sold directly from the farm or whether it is fed to animals and the products such as live stock, beef, pork, wool, eggs, or milk, used as the source of revenue. If the crops now produced on two hundred acres of land could be grown on one hundred without a great increase of labor and other expense, the profit would be greater. Successful farmers have demonstrated that the present average of crops can be doubled, and that at a cost per acre scarcely more than is now required for the one-half crop.

To accomplish this requires a broader knowledge of the food requirements of plants than is possessed by most of our farmers. A thorough understanding of the subject of plant food and plant nutrition by our forerunners in agriculture would have rendered it unnecessary to emphasize constantly the relation of the constituents of the plant to soil exhaustion.

It is common experience that continued cropping results in a loss of fertility. The productiveness of a virgin soil seems unlimited, for large crops are produced from year to year with no apparent decrease. But sooner or later they begin to diminish in size, gradually to be sure, but unceasingly, until at last the yield becomes so small as to make the cost and labor of production unprofitable.

At the Experiment Station at Rothamsted, England, barley grown continuously on the same plot for forty-three years without the use of fertilizers of any kind, yielded in the forty-third year 10 bushels of dressed grain per acre, the average for the last eight years being $11\frac{3}{4}$ bushels. Wheat grown for fifty years

in the same way produced in the fiftieth year $9\frac{3}{4}$ bushels of grain per acre, the average for the last eight years being $11\frac{1}{2}$ bushels. The soil seems capable of keeping up the yield indefinitely, but the amount of crop produced ceases to be profitable.

It is evident that the virgin soil must have contained large amounts of some substances that were necessary for vigorous plant growth and that these were removed by the successive crops when harvested. The rapid decrease in fertility finds its most rational explanation on this basis. Changes in climate and physical condition of the soil are inadequate as explanations for this decreased productive power.

A description of the elements important to agriculture has already been given and the very reason for their importance to the farmer lies in the fact that they are the elements which constitute the compounds of plants and are removed from the soil when the crop is harvested.

Source of elements. However, not all of the elements described have come from the soil. Plants obtain the elements of which they are built up partly from the soil and partly from the atmosphere. From the soil they obtain by means of their roots all their ash constituents, all their sulphur and phosphorus, and in most cases, nearly the whole of their nitrogen and water. From the atmosphere they obtain, through the instrumentality of their leaves, the whole or nearly the whole, of their carbon. There are exceptions, especially in regard to nitrogen, which is obtained from the atmosphere by certain plants, such as alfalfa, clover, vetch, pea and bean, under certain conditions to be described later.

Composition of the plant. The most abundant ingredient of a living plant is water. Many succulent vegetables, as the turnip and lettuce contain more than ninety per cent of water. The green corn plant contains eighty-five to ninety per cent of water.

Combustible part of plants. If a stalk of corn is dried and burned the greater part is consumed and passes away in the form of gas. But there is always left behind a small quantity of white

ash, corresponding exactly to the ash left in the stove after a stick of timber is burned.

The constituents which form the dry matter of plants may be divided into two classes—the *combustible* and the *non-combustible* part. The combustible part of plants is made up of six chemical elements—carbon, oxygen, hydrogen, nitrogen and sulphur, with a small amount of phosphorus. Without these no plant will grow. Carbon generally forms about one-half of the dry combustible part of plants. Nitrogen seldom exceeds four per cent of the dry matter and is generally present in much smaller amounts. Sulphur and phosphorus are still smaller in quantity. The remainder is made up of oxygen and hydrogen. The carbon, hydrogen and oxygen form the cellulose, starch, lignin, gummy matters, sugars, fats and vegetable acids which plants contain. The same elements united with sulphur and nitrogen form the very important proteins, which are the life centers of the plant. When all the above elements are united to phosphorus, we have additional important groups of plant compounds, called nucleins and lecithins.

Non-combustible part of plants. The non-combustible or ash constituents form generally but a small part of the plant. A fresh, mature corn plant will contain about 1.2 per cent of ash, while the corn grain when dry, contains about 1.5 per cent. In the straw of cereals the ash constitutes 4-7 per cent and cereal grains 2-3 per cent of the dry matter. In hay 5-9 per cent will be found. We find in leaves, especially old leaves, the greatest proportion of ash. In the leaves of root crops the ash will amount to 10-25 per cent of the dry matter.

Essential elements. The non-combustible ash always contains six elements—potassium, magnesium, calcium, iron, phosphorus and sulphur. It was once thought that these ash elements were accidental, simply dissolved in the soil water and absorbed by the plant and that they were not essential to its development. Liebig proved that they were necessary; seeds were planted in pure quartz sand contained in a series of pots to one of which nitrogen

compounds alone were added, and to the others, nitrogen compounds plus a small amount of plant ash. The plants in the pots which received the ash grew to maturity, while those in the other pots made only a feeble growth.



Water cultures of buckwheat. This method of experimental culture, which is known as water culture, has been of the greatest service in determining which elements are essential for plant growth.

No. 1. Plant grown in normal solution.

No. 2. Plant grown in normal solution without potassium.

No. 3. Plant grown in normal solution with sodium instead of potassium.

No. 4. Plant grown in normal solution without calcium.

No. 5. Plant grown in normal solution without nitrogen.

Non-essential elements. Besides the elements just named an ash will generally contain sodium, silicon, chlorine, and frequently manganese, and perhaps minute traces of other elements. These elements just named sometimes form a considerable portion

of the ash. For the reason that plants have been brought to maturity in their absence, it has been generally accepted that they are non-essential. However, it is necessary to remember that such experiments have generally extended over a single generation and that it is possible that an attempt to grow the crop through successive generations from its own seed in a soil devoid of sodium, chlorine, silica, or manganese might meet with failure.

How ash elements occur. The ash elements named above occur in part in the plant as salts, being combined with phosphoric, nitric, sulphuric and various vegetable acids of which acetic, oxalic, malic, tartaric and citric acids are the most common. It is also very certain that part is in combination with the organic or combustible part of the plant. Sulphur occurs partly as sulphates and also as a constituent of proteins. Phosphorus as a phosphate in the stem and root of the plant, but in organic form in its seeds. In addition, such ash elements as potassium, magnesium, calcium, iron and silicon are very probably in part constituents of the organic compounds of plants.

It is usual to speak of the combustible ingredients of a plant as organic, and of the non-combustible ingredients as inorganic. This is not accurate, as these ash constituents, which are essential for the growth of the plant, have during its life as much right to be called organic as the carbon of starch or protein.

Can one element displace another? The fact that some of the elements found in plant ash, as sodium and potassium, are chemically very much alike, has led to the attempt to displace the expensive and less commonly occurring potassium by the inexpensive and relatively abundant element, sodium. If it were possible to do this, the farmer's fertilizer bills for potassium salts would be materially reduced. However, experiments have demonstrated that sodium cannot take the place of potassium in the growth of the plant.

A definite amount of all the essential elements is needed for a certain yield and none of the elements can be replaced by another. A crop will be limited by the quantity of the essential element

present in least quantity compared with the requirements of that crop. If a field of corn can obtain only potash enough for a half crop, no more than this can be produced, no matter how much of the other forms of plant food is present.

The following table shows the ingredients, expressed as pounds, in 1000 lbs. of the matured corn plant, when the plant is to be cut for shocking:

Corn Plant 1000 lbs.	{	Water	{	Hydrogen ...	88.1		
		798	{	Oxygen.....	704.9		
	{	Organic matter 195	{	Protein	18	{	Nitrogen 2.9
				Fat	5	{	Carbon 90.5
				Fibre	50	{	Oxygen..... 88.9
{	Dry matter 207	{	{	Carbohydrates ..	122	{	Hydrogen..... 12.7
				Chlorine	0.4		
				Potash.....	4.0		
				Phosphoric acid.	1.2		
				Lime	1.6		
				Magnesia ..	1.4		
				Iron oxide.....	0.3		
				Sulphur trioxide.	0.3		
{	Ash 12	{	{	Soda.....	0.4		
				Silica.....	2.4		

All the elements mentioned above as occurring in the ash, with the exception of chlorine, are combined with oxygen. In the table the names under "ash" represent these combinations: potash is composed of potassium and oxygen; phosphoric acid of phosphorus and oxygen; lime of calcium and oxygen; sulphur trioxide of sulphur and oxygen.

The table shows that three elements, hydrogen, oxygen and carbon, make up 98½ per cent of the entire composition of the plant, the remaining elements constituting only 1½ per cent.

CHAPTER II

THE ATMOSPHERE

The atmosphere or air forms an invisible envelope surrounding and resting upon the earth. It's exact thickness is unknown, for it blends gradually with the imperceptible ether which fills interplanetary space. While its functions are less apparent than those of water and soil, it nevertheless bears important relations to agricultural life and industries.

Weight of the air. The resistance which air offers to rapidly moving bodies, its own motion as wind and the support of clouds and other bodies are evidences of its mass. The pressure by which it forces water into the vacuum of a pump or balances a column of mercury in the barometer is a measure of its weight, which is approximately 15 pounds per square inch at sea level, or 41,300 tons for each acre of the earth's surface. Were the air of uniform density throughout, its height could be easily measured. The barometer falls, however, with decreasing rapidity as it is raised from the earth, thus proving that the air decreases in density with increase in height.

Height of the air. The band of haze attending the earth's shadow at lunar eclipse, the twilight period upon the earth, the time of falling meteors and other phenomena dependent upon the atmosphere give means of estimating its approximate height as at least 200 miles.

Air essential to life. If an animal be enclosed with a supply of food in a perfectly tight chamber but with a limited supply of air it will finally suffocate. This occurs as a result of exhausting the greater part of a constituent of the air known as oxygen. This element is absolutely essential to the processes by which food is assimilated and waste matter is expelled from the animal body. So too, if a plant be similarly enclosed, it will finally cease to grow and prematurely die. This is because it exhausts the limited sup-

ply of carbon dioxide, a constituent of the air, which is the basal material for all compounds made by the growing plant. The burning of wood is a chemical process in which oxygen of the air unites with the chemical constituents of the wood. If the fire be banked or otherwise deprived of a liberal air supply, it smoulders. When air is liberally supplied, as through the stove drafts or forge bellows, combustion—and the resultant heat—are greatly increased, as a consequence of the increased supply of oxygen. The formation of humus in the soil, the fermentation of manures, and many other common phenomena of the farm, are in part processes of oxidation or burning on a small scale, and are dependent upon proper supplies of the oxygen of the air.

Atmosphere controls rainfall. The atmosphere contains varying amounts of water. Warm air has great capacity for holding water and may take up large amounts from the sea and inland lakes. Movements of this water-laden air control rainfall. In the case of the warm, moisture-laden winds moving eastward from the Pacific ocean, the water is released when the air is cooled on the snow clad summits of the Rocky Mountains. As a result, a large area east of the mountains, known as the Great American Desert, receives little or no rainfall and farmers are forced to irrigate or practice dry farming on arable land of this region.

Atmosphere controls temperature. Dry air transmits heat readily from the sun to the earth or from the earth into space. For this reason the temperature falls rapidly after sunset in dry winter weather. Dry air also permits rapid evaporation of water from the earth's surface with consequent cooling. Moist air, on the other hand, prevents rapid evaporation from the earth's surface, absorbs heat transmitted from the sun and radiated from the earth, and thereby maintains higher temperatures.

While the phenomena of temperature, moisture content, and movement of the air do not directly involve chemical processes, they have fundamental significance in the supplying of water and the maintaining of temperatures which regulate the chemical processes of plant growth. This significance has been a prominent

factor in the development of the present extensive Weather Bureau service of the United States government. The records of this Bureau are of great service not only in predicting storms and frosts, but in mapping restricted areas, such as the sugar beet belt, which will be favorable for certain crops dependent upon uniform temperature and proper amounts of sunshine and rainfall.

Air is a mixture. A chemical compound is characterized by uniform composition. That is, the constituents of a single compound occur in the same proportions throughout its mass. This is not true for air, as the following table shows:

Percentage Composition of the Atmosphere at Different Levels.

Height in feet	3280	32,800	65,600	164,000	328,000
	Per cent	Per cent	Per cent	Per cent	Per cent
Nitrogen.....	78.04	81.05	85.99	89.62	95.35
Oxygen.....	20.99	18.35	13.79	10.31	4.65
Argon.....	0.94	0.58	0.22	0.07	0.00
Carbon dioxide.....	0.03	0.02	0.004	0.00	0.00

The air is a mixture of water vapor, gases, and solids in which the gases form far the greatest part. Since it is a mixture, the constituents are free to separate and, as the above table shows, the heavier constituents are absent in the higher layers.

Composition of air. The average composition of dry air is as shown in the table on page 26.

Water of the atmosphere. The water used by plants is taken up from the soil by way of the roots. Its passage through the plant and the escape of excess of water are regulated by the process of transpiration or evaporation from the surface of the leaves into the air. From the current of water thus maintained from the soil to the plant, growing crops assimilate all of their food except carbon dioxide. When the air is dry it absorbs water readily and promotes transpiration. Moist air, on the contrary,

retards transpiration. By these influences over transpiration the air exercises control over plant growth.

As has been stated, the presence of water in the air increases its capacity to absorb heat and when the air is cooled it loses its power to retain moisture. Water then separates from it and collects upon colder objects. This is the cause of the appearance of drops of water on the outer surface of an ice-water pitcher on a sultry day in summer. Dew is formed in the same manner. After sunset on a warm summer's day the earth cools rapidly by radiation and reaches a temperature below that of the adja-

The Average Composition of Dry Air.

	Per cent. by weight Lbs. per 100 lbs. of air.	Per cent. by volume Gals. per 100 gals. of air.
Gases: Nitrogen	75.5	78.0
Oxygen	23.0	21.0
Argon	1.0	0.94
Carbon dioxide....	0.04	0.03
Ammonia	Trace	Trace
Nitric acid	"	"
Ozone	"	"
Solids: Dust	"	"
Bacteria	"	"
Salts	"	"

cent air. At a temperature bearing a definite relation to the moisture content of the air and known as "the dew point," moisture leaves the air and collects upon the surface of vegetation and other cool objects. In rainless regions dew becomes an important source of water for crops and frequent tilling must be practiced to prevent its escape by evaporation from the surface of the soil.

Movements of the moisture laden air distribute rainfall over the land; and some of the less prominent constituents of the air are washed to the soil by rain and become factors in the supply of plant food.

Gases of the air. Dry, pure air is essentially a mixture of gases. A gas differs from the more familiar forms of matter, as liquids and solids, in that its particles are much farther removed from one another, or as we say, it has less density. This relation is illustrated by the different forms which water may assume. When the solid substance known as ice is heated, its particles spread farther apart until it no longer has sufficient cohesive power to retain its shape. It then melts and becomes the liquid known as water. Sufficient further heating, by separating the particles of water still farther apart, transforms it to the state of an invisible gas known as steam, which becomes a constituent of the gaseous atmosphere. When steam comes in contact with cold solid objects, or even with cold air, it contracts or condenses to visible water vapor. The gases of the air maintain their rarified form under all ordinary conditions. They can be converted, however, like the air itself, to liquids, and even to solids, by subjecting them simultaneously to very low temperatures and high pressures.

Nitrogen. This is the most considerable constituent of the air and amounts to more than three-quarters of the total weight, or about 30,000 tons over every acre of land. It is characterized by extreme inertness. When combined in chemical compounds it is frequently held with difficulty. High power explosives depend for their value upon the ready and sudden release of a large volume of gaseous nitrogen from less bulky compounds as nitro-cellulose and nitro-glycerine. Since nitrogen is an essential constituent of compounds of the greatest importance in the living cells of plants and animals, its ready escape from such compounds has presented one of the greatest problems of agriculture.

Relation of nitrogen to plant growth. The work of several able investigators has proved conclusively that higher plants cannot draw directly upon the great stores of nitrogen in the air for their supply of this element.

In 1855 the French chemist Boussingault announced the results of a series of carefully performed experiments to determine

this point. He grew plants for one and one-half to five months with no nitrogen supply beyond that in the seeds and the free nitrogen of the air. The seed was sown in a soil composed of ignited pumice stone and the ashes of manure, both having been freed from nitrogen compounds. The plants were grown in a glass jar sealed from the air but in connection with a supply of carbonic acid and were provided also with water free from nitrogen. At the end of the experiments the nitrogen was determined in the plants and soil.

The following table gives the results of five of the experiments and the average of the series:

Kind of Plant.	Nitrogen in Seeds.	Nitrogen in Crop and Soil.	Gain (+) or Loss (-) of Nitrogen.
	gms.*	gms.	gms.
Bean	0.0349	0.0340	-0.0009
Oat	0.0031	0.0030	-0.0001
Lupin	0.0200	0.0204	+0.0004
Lupin	0.0399	0.0397	-0.0002
Cress	0.0013	0.0013	0.0000
Sum of 14 Experiments.....	0.6135	0.5868	-0.0247

*A gram is about one-twenty-eighth of an ounce.

Since the gains or losses of nitrogen are within the limits of experimental error, Boussingault concluded, as a result of his work, that plants cannot use the free nitrogen of the air.

This work was disputed by Ville, also of France, who grew plants in larger chambers and renewed the supply of air. He criticised Boussingault's work for the limited amount of air used. Boussingault then proved by further experiments that plants raised under the conditions of his earlier trials only attained full development when supplied with assimilable *compounds* of nitrogen. An investigation of Ville's experiments then showed that his results were vitiated by the presence of ammonia in his apparatus.

The problem concerning the assimilation of free nitrogen was finally settled by an exhaustive study made in 1857 to 1858 by Lawes, Gilbert and Pugh at the Rothamsted Experiment Station in England. These investigators completed 27 experiments with cereals, legumes and buckwheat. The plants were grown under glass jars inverted in mercury to isolate them from the air. A supply of air, freed from nitrogen compounds and mixed with carbonic acid was forced through the apparatus and all nitrogen compounds were carefully excluded from the soil and water used in these experiments. The results fully confirmed the conclusions of Boussingault.

In the course of other experiments it was observed that while supplies of nitrogen *compounds* in the soil stimulated the growth of cereals, they were without appreciable effect upon legumes. It remained for the German bacteriologist, Hellriegel, to demonstrate that leachings from soils cropped to legumes stimulated the growth of these crops on infertile soils, but failed to affect cereals. Then followed the discovery of a remarkable affiliation of bacteria and leguminous plants by which the plants obtain supplies of nitrogen from the atmosphere. This discovery finds a practical application in the growth of leguminous crops in rotations for the purpose of maintaining the supply of nitrogen in the soil. In field experiments the soil supply of nitrogen has been maintained by growing clover in rotation with cereal crops. A small amount of nitrogen compounds also accumulates in the soil by the growth of bacteria which thrive independently of higher plants.

Oxygen. This constituent of the air is prominent among the chemical elements because of its extreme activity. It combines with the waste products from plant or animal life in the process of combustion or decay and makes possible their destruction and removal. This process is frequently accompanied by perceptible heat, as in the rapid combustion of fuels, or the less active combustion of manures and silage. It is the source of heat in the animal body. The hardening of so-called "drying-oils" is also

a process of oxidation. These combine with the oxygen of the air, in some cases with sufficient rapidity to produce a rise in temperature causing spontaneous combustion. Destructive fires occasionally result from such oxidations.

Oxygen usually forms about 23.2 per cent of the air by weight. Where animal life is abundant or where much putrefaction is in progress, the percentage of it in the air will be reduced. On



Clover obtaining its necessary nitrogen from the air through the action of certain bacteria. No. 5 contains these bacteria, while No. 6 does not (after Russell and Hastings).

the other hand, being exhaled by plants, its proportion may increase slightly where vegetation is abundant.

Argon. This gas forms most of the remainder of the air. It closely resembles nitrogen in its properties. Argon is not known to be of any importance to agriculture.

Carbon dioxide. Although usually forming a very small fraction of the air—0.04 part, or less, by weight in 100 parts of air—this constituent is of great importance in agriculture. The average green corn crop of 12 tons per acre requires for its production 4 tons of carbon dioxide, which necessitates the respiring of 10,000 tons of air, or about $\frac{1}{4}$ the amount available over that

acre. This supply of carbon dioxide is assimilated from air taken in through the leaf pores or stomata. When united with water brought from the roots, it forms the basal compounds of the plant. The removal of this gas by plants is offset by its return from processes of combustion, fermentation, and animal respiration so that there is maintained a nearly constant proportion in the air. When produced by the decay of humus-forming material, it dissolves in the soil water and becomes a leading factor in liberating plant food from the mineral compounds of the soil.

Ozone. This gas bears the relation to oxygen of $O_3—O_2$ —where O_2 is the molecular symbol for oxygen. It is one-half more concentrated than oxygen and as a consequence is much more active. Ozone occurs in the air as a result of the action of electrical discharges upon oxygen. It acts as an antiseptic by attacking and destroying bacterial matter. Because of its great activity, it is rapidly exhausted and never amounts to more than a trace in the atmosphere.

Nitric oxide. Traces of this gas accumulate in the wake of electrical storms. It is a compound of one part of nitrogen with one part of oxygen (14 parts of nitrogen with 16 parts of oxygen by weight), the formation of which is induced by electrical discharges. Nitric oxide readily unites with oxygen and water to form nitric acid and washes to the soil in the rain. Knop found ordinary rain water at Leipsig, Germany, to contain 56 pounds of nitric acid in 10,000,000 pounds of water, while rain which fell during a thunder shower contained 98 pounds in 10,000,000. Nitric acid brought to the earth in this way is not free but combined with ammonia in the air. Reaching the soil as ammonium nitrate it is directly available to the plant.

Ammonia. This gas accumulates in traces in the air as a result of the decay of organic nitrogenous compounds. It is produced in considerable amounts by the rapid fermentation of manures and in such cases may be detected by its pungent odor. It dissolves readily in water and washes to the soil in rains, generally in combination with nitric acid. In this form its nitrogen

may be used directly by the plant or ultimately converted to nitrates. Ammonia from this source contributes but a small part of the nitrogen required by crops.

The average amount of nitrogen brought to the soil per acre yearly by rain at the Rothamsted Experiment Station, over a period of 18 years was as follows:

Nitrogen as nitrates and nitrites.....	1.1 lbs.
Nitrogen as Ammonia	2.6 lbs.
Nitrogen in organic forms.....	1.0 lb.
Total nitrogen.....	4.7 lbs.

Obviously this supply of nitrogen falls far short of the 50 to 100 pounds of nitrogen per acre required by different crops.

Solids. The solids usually present in common air are substances which have been taken up by the wind and remain suspended in finely divided condition. They include bacteria, yeast spores and other microscopic forms of plant life. These furnish the nitrogen already referred to as brought to the soil in "organic forms." The air contains dust particles from finely divided soil and this constituent is prominent in dry regions. Spray from bodies of salt water, when taken into the air by wind, evaporates and leaves small quantities of salts suspended. These consist principally of sulphates and chlorides of sodium, potassium, calcium and magnesium. Salts may be returned to the soil by rain in considerable amounts near the sea coast. Common salt is brought to the soil in this manner at the rate of 186 pounds per acre yearly at Georgetown, British Guiana; at Rothamsted, England, which is farther inland, the amount is about 24 pounds per acre. Sulphur is an important element in the growth of plants, and is brought to the soil by rain in the form of sulphates taken up from the sea. These supplies of plant food may become important factors in the growth of crops. It has been estimated that the chlorine in rain water at Rothamsted is sufficient for crops, with the possible exception of mangels, and that the sulphur supplied in this way meets the demands of most cultivated crops. This high supply of sulphur may, however, be derived

partly from extensive soft coal burning in a country like England. It is extremely doubtful if the sulphur supply from the atmosphere in the open country of the United States is as high as that found at Rothamsted. It is very probably much lower and not nearly sufficient for continuous crop requirements.

Accidental constituents. In some localities the air contains uncommon constituents as a result of local conditions. This is true in active volcanic regions and in the vicinity of some indus-



The effect of smelter fumes and waste on vegetation near Anaconda, Montana.

trial plants. The most important of these constituents are gases. Methane or marsh gas, which is a product of fermentation where air is excluded and which accumulates over swamps and in mines, and carbon monoxide, a product from the incomplete combustion of coal, are examples of this class. Hydrochloric acid gas, which escaped into the air in quantity from the old process of manufacturing soda, is an example of an objectionable, accidental constituent of the air resulting from an industrial process. The deadly effect of this gas upon vegetation led to the passage of

laws restricting its escape. It is now condensed in the factory as a by-product of the industry.

Sulphur dioxide is an accidental gaseous constituent of the air, the effects of which are of economic importance. It is expelled from the stacks of smelters roasting ores which contain sulphur. It is also produced in small amounts wherever the combustion of coal takes place. It may be partially converted to sulphur trioxide and brought to the soil by rain as a supply of sulphur for plants. The amount in the rain at Rothamsted was found to be about 17 pounds of sulphur trioxide yearly per acre.

Experiments have demonstrated that sulphur dioxide injures plants through their leaves. Fumigation with one part of the gas to 100,000 parts of air has been fatal to scrub pines. Investigations have shown it to be the cause of serious injury to the vegetation in the vicinity of copper smelters in California, Montana and elsewhere. The foliage of injured trees in these vicinities was found to contain more sulphur than that of normal trees. Peach trees in an exposed position nine miles from a smelter at Redding, California, and red firs at a distance of fifteen miles from the Washoe smelter, Anaconda, Montana, were badly injured. Analysis of the smoke from the latter smelter showed an output of 5,000,000 pounds of sulphur trioxide per day. Haywood, of the Bureau of Chemistry, concludes that these fumes can be condensed and the products probably readily marketed. Legislation in the interests of forestry should restrict the escape of this gas as it has in the case of hydrochloric acid.

CHAPTER III

THE SOIL.

Soil is the layer of disintegrated rock, mixed with the remains of plants, which covers a large portion of the land. It also contains living organisms of various kinds and variable quantities of water and air. The depth of soils varies greatly, being usually from six to twelve inches, and sometimes as great as several feet. Beneath it is the subsoil which differs from the upper layer in containing less organic matter. The line of demarcation can often be distinctly seen in deep trenches by the difference in color, the subsoil being generally of lighter color, and gradually grading into the dark color of the upper soil.

Soils consist largely of disintegrated rock fragments and depend for their chemical nature mainly upon the character of the rocks beneath. The rocks have been classified by geologists according to their origin into three classes:

(1) *Igneous rocks* are those which resulted from the cooling of intensely heated matter. The granites represent this type.

(2) *Sedimentary rocks* are those resulting from the settling out of particles suspended in water. Limestones are examples of this type.

(3) *Metamorphic rocks* are those which have been changed in character since their deposition. The conversion of limestone into marble by pressure and heat is an illustration of this type.

These rocks must have contained all of the mineral or ash elements of plant food as no other source for them is conceivable.

Rocks are rarely homogeneous, that is, alike in all parts—but are generally made up of several components mingled together, often lying side by side as separate crystals. These components, which have a more or less definite composition, are called minerals. Distinctly separate minerals are more frequently to be seen in the igneous rocks. A piece of granite will readily show that it is made up of several distinct minerals.

Minerals. The following minerals are abundant and of the greatest importance to agriculture:

Quartz is chemically a compound of silicon and oxygen. It is estimated that it forms 35 per cent of the solid crust of the earth. It is one of the hardest and most durable of substances and is practically insoluble in water and but little affected by the weather. Sea sand and the sands along the shores of our fresh water lakes are often almost wholly made up of fine grains of quartz, worn smooth by continuous agitation to which they have been subjected. Fragments of quartz, consisting of crystals rounded and worn by mechanical rubbing against each other, form the largest constituent of many soils. Such sand is lacking in plant food.

Feldspars are probably the most abundant of all minerals and constitute, it is estimated, 48 per cent of the earth's crust. Chemically, the feldspars contain silicon, oxygen and aluminum in combination with either sodium, potassium, or calcium, and are called by the chemist, *silicates*.

The chief varieties of feldspars are

Orthoclase	potassium	aluminum	silicon	oxygen
Albite	sodium	aluminum	silicon	oxygen
Labradorite	sodium	aluminum	silicon	oxygen
	calcium			

Orthoclase or potash feldspar is the most important. It is a hard mineral, often colored pink or green, though sometimes white. Although hard, it is easily attacked by water and carbon dioxide, the potassium being largely removed in solution while the final residue is kaolin or China clay. Orthoclase furnishes a considerable quantity of the potash found in our soils.

Mica is another abundant mineral and characterized by its tendency to split into thin elastic plates. It is essentially a compound of aluminum, potassium, silicon and oxygen, though it usually contains iron and often calcium or magnesium. Mica also suffers decomposition under the influence of the weather, but not so readily as the feldspars. It furnishes plant food in

the iron, potassium and calcium it contains. Its amount in the earth's crust has been estimated at 8 per cent.

Silicates of magnesia are also very abundant. Talc and steatite are representatives of this class and are compounds of magnesium, silicon and oxygen, designated by the chemist "silicates of magnesia." They also contain water. When the magnesium is partly replaced by other elements, as calcium, iron or manganese, we have the distinct minerals known as hornblende and augite. All the minerals of this class are easily acted upon by water and air and often yield brightly colored clays due to the presence of iron.

Calcium carbonate occurs in a great many crystalline forms, the principal variety being called calcite, and in the massive form is known as chalk, limestone and marble. These are all essentially made of calcium, carbon and oxygen, but in certain localities the calcium is more or less replaced by magnesium which then gives us the mineral known as *dolomite*. This is true of many of the "limestones" found in Wisconsin. Most calcium carbonates contain notable quantities of phosphoric acid. Calcium and magnesium carbonates, though only slightly soluble in pure water, are readily soluble in water containing, as in the case of nearly all forms of natural water, carbon dioxide. Rocks containing these substances therefore are quickly eroded by exposure to the atmosphere. Calcium carbonate is of great importance in soils, both on account of its providing plant food and because of its relationship to many of the processes which go on in soils.

Clay in its pure form is a hydrated silicate of aluminum and is therefore devoid of plant food. By the term hydrated we mean that the compound of silicon, aluminum and oxygen (silicate of aluminum) is joined to a certain amount of water. Ordinary clay, however, contains iron and potassium, the latter remaining from the feldspar, from which most clays have been formed. It therefore supplies potassium to plants. Its physical properties are very important and greatly influence soils in which it is abundant.

Apatite or crystalized phosphate of lime, is present in small quantities in many of the older rocks, and is probably the original source of the phosphoric acid of soils. Apatite also occurs massive in some of the older rock formations and is mined as a raw material for the manufacture of phosphate manure in Norway, Canada and particularly in some of our southern states, as Florida, the Carolinas, Georgia and Tennessee.

A brief description of some of the more important rocks will now be given. The igneous rocks are the oldest and it was from the debris of igneous rocks that sand stones, shales and, indirectly, limestones were formed.

Sand stones and grits, consist of the larger fragments of the waste resulting from the breaking up of igneous rocks, as for example granite, which in consequence of their size and weight have been deposited at or near the mouths of rivers. Their main ingredient is silica, the grains of sand consisting largely of quartz crystals, but in many cases fragments of feldspars, mica and other minerals are present. These grains are cemented together either by calcium carbonate, as in calcareous sand-stones, by clay, as in argillaceous sand-stones, by iron oxide, as in ferruginous sand-stones, or by silica, as in siliceous sand-stones. Soils produced by the decay of sand-stones are light and friable and poor in plant food unless there is present potassium-containing minerals as feldspar and mica.

Shales consist principally of the plastic hydrated aluminum silicate, kaolin, but may contain any other extremely finely divided matter obtained by the erosion of the original rock. Particles of undecomposed or partially decomposed feldspars are often present and these are of importance because of the potash they contain. Soils formed from shales are "heavy" and clayey, generally sufficiently rich in potassium, but poor in phosphorus and calcium carbonate (lime).

Limestones, in which term chalk and magnesian limestone may also be included, have been formed largely by the abstraction from water by living organisms, as coral polyps, shell fish, etc.,

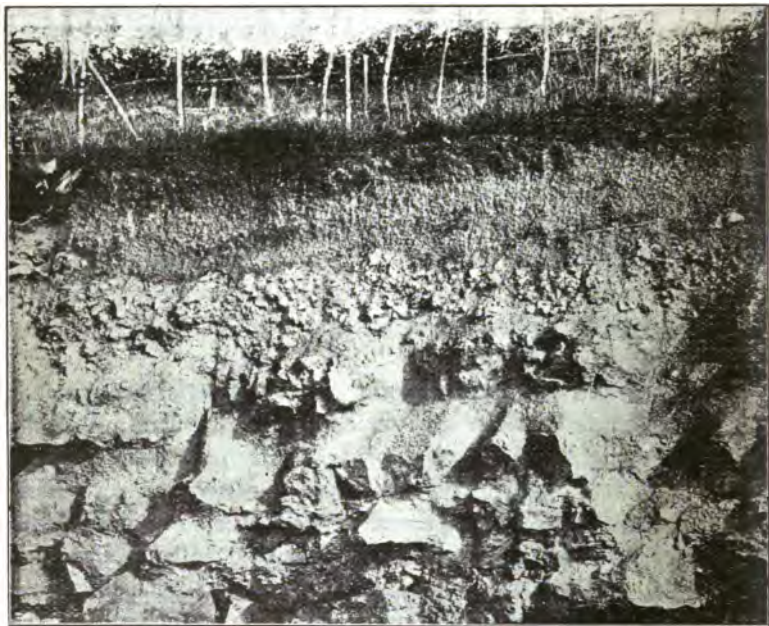
of calcium and magnesium carbonates. Oyster shells are principally a calcium carbonate. Limestones often contain small quantities of clay, iron oxide, silica and nearly always calcium phosphate in comparatively large quantities. The soil left on limestone or chalk consists mainly of these foreign substances, most of the calcium carbonate itself having been dissolved out by the combined action of water and carbon dioxide. It sometimes happens therefore that the soil originating on limestone would be benefited by an application of limestone.

Limestone only exerts its characteristic and important functions in a soil when in a very finely divided state. In the form of gravel or sand it is little better than ordinary siliceous sand. In the finely divided state it has two very valuable functions; first, as a source of plant food by virtue of the calcium which it contains, and second, which is more important, as a basic material necessary for the correction of an acid reaction in the soil and for the processes of nitrification.

Sedentary and transported soils. These terms are convenient in distinguishing between soils which have been made up of the debris resulting from the weathering of the particular rock on which they rest (sedentary soils) and those which owe their origin, not to the rock below them, but to materials brought from a distance and deposited there (transported soils). The rich alluvial soil in the lower reaches of river valleys consists largely of material which has been brought down by the river from the higher parts of the valley and since the materials in many cases have been brought from various rock formations, the resulting soil generally possesses a greater fertility than would be shown by soil formed exclusively by the weathering of any one kind of rock.

Glaciers are also the means of transporting large quantities of materials out of which soils may be formed. Large tracts of country are covered with a thick deposit of clay and rock fragments, which have been brought from a great distance by glaciers. Such deposits are known as glacial drift, and often quite obscure

the actual rock beneath. In this case the transportation of the soil took place many ages ago. A large part of northern United States is covered by drift, which was pushed down from the north by the glaciers that once covered that section and was left behind as the ice melted away. Such soils are distinguished from all



The weathering of rock into sub-soil and soil (after Hall).

others by the presence of rounded boulders of various sizes. They are usually fertile, although very variable in composition.

Wind also sometimes acts as a means of transporting sand, volcanic ash, etc., from a distance and deposits them in a new position, there to form a soil.

Formation of soil. In the formation of a soil the first step is the mechanical breaking down of the rock into small fragments.

The chief agencies by which this is accomplished are, first by *Water*, which acts in several ways.

Mechanically, by liquid water—The flow of water over the surface of a rock abrades it slightly. The action is greatly increased by the rubbing action of pebbles and gravel, urged on by the current over the rock. In this way streams in the rapid portions of a course carry away large quantities of sand, gravel, etc., and deposit them in the lower and quieter portions of their course as alluvial deposits. **By glaciers**—Glaciers are slowly moving masses of ice. In their descent, aided by fragments of rock imbedded in them, they grind away the rock over which they pass and the stream which flows from the base of a glacier is always heavily charged with the finest mud, while the lowest point reached by a glacier is marked by huge piles of rock fragments of all sizes, carried down on the surface of the moving ice. **By alternate frost and thaw**—Ice occupies a greater volume than the water from which it is formed. The increase in volume in the act of freezing amounts to about 10 per cent and unless this increase is allowed to occur water cannot freeze, however much it be cooled. This is a powerful agency in the pulverization of rocks. All rocks are more or less porous and absorb water. During the warm part of a wet winter's day the crevices of a rock become filled with water. If the temperature falls the water begins to freeze, at first on the surface so that every crevice becomes plugged with ice. As the liquid within continues to lose heat it tends to solidify. This it can only do if it be allowed to expand and in order to do this it must widen or lengthen the crevice. When the next thaw comes, the enlarged crevice again fills with water. The next freeze repeats the action and so the process goes on until the hardest rock is broken into fragments.

Chemically. Many minerals when exposed to the action of water are acted upon in such a way as to lead to their disintegration. A portion is often carried away in solution while the remainder crumbles and is then easily moved by rain or running water. In many rocks the cementing material, which holds the

grains together, is dissolved away and the residual fragments then readily crumble.

A soil produced by mere mechanical pulverization of the rocks would not furnish proper food for the higher plants. This can readily be imagined if one thinks how unsuitable crushed granite would be for plant production. The essential elements locked up in these insoluble soil-forming materials must be changed into materials that the plant can assimilate and water is an important factor in bringing about such chemical changes. The minerals forming our igneous rocks are, however, very slightly soluble in pure water; but the water that enters the ground has dissolved in it small amounts of carbon dioxide, derived from the air, and water containing this gas will dissolve these minerals in appreciable quantities.

Another important agent in soil formation is the *air*, which acts in several ways.

Mechanically. Wind actually detaches large projecting pieces of rock in mountainous districts and sends them crashing down onto the rocks below. In addition, by hurling sand and small pebbles against the surface of rocks it brings about the erosion of the latter. In most cases the effects of this form of erosion are masked and hidden by those of other denuding agencies.

Chemically. In many rocks are minerals capable of taking up oxygen. On exposure to air, oxidation occurs and the mineral swells up and often crumbles to powder, thus loosening the other minerals in the rocks. This oxidation is in many cases accompanied by a change in color, from green or gray to yellow or red. The carbon dioxide of the air also acts corrosively on carbonates in the presence of water.

Animals are also important agencies in soil formation. Burrowing animals, as for example, rabbits, moles, etc., admit air into soil or sand and thus favor the changes which air produces. The part played by the humbler creatures, earth worms, is probably much more important. They bring portions of the subsoil to the surface, they draw dead leaves and other vegetable refuse

into their burrows, and they pass large quantities of the soil through their bodies and deposit it on the surface at a rate which has been estimated on the average to be about ten tons per acre per year.

Ants in some hot countries, as for example Africa, perform much the same work as earth worms, though perhaps on even a larger scale. Ingle says that in many parts of South Africa, the veld is thickly studded with the hills of the white ant, usually about two feet high and about two to three feet in diameter, though much larger ones are often found. The ant hills are full of cavities and chambers inhabited by the insects and much vegetable matter is stored in them. The material of the ant hills consists of the smaller parts of the surrounding soil, the particles being cemented together and the whole made practically water tight. When the veld is plowed and sown, it is always noticed that where ant hills had formerly been the crop is heavier than elsewhere.

Plants act as soil formers in several ways: *Mechanically*—the roots penetrate the rocks or soils, rendering them porous and thus admitting air and water. They also exert a tremendous lateral force, breaking apart rocks and stones when once they have obtained a foothold in a crevice. The roots penetrate the soil sometimes to great depths, and as they decay, after the death of the plant, they leave in the soil little channels, which serve to carry down water laden with carbon dioxide, as well as the oxygen of the air, which as previously pointed out are important factors in soil making and the production of available plant food. *Chemically*—plants act during life through the corrosive action of the carbon dioxide excreted by the roots and root hairs and after death by producing carbon dioxide and various vegetable acids, which have solvent properties upon certain constituents of soils.

The formation of a mass of pulverized rock, however, is not all that is necessary for producing a fertile soil. *A fertile soil must contain nitrogen.* It has been shown that to grow crops the

soil must contain available nitrogen, and this must have been derived originally from the air. Small quantities of combined nitrogen, as stated in a previous chapter, are carried into the ground by the rain water and though small in amount, are probably sufficient to enable plant growth to begin. Bacteriologists believe that certain species of bacteria, which can live on mineral food alone and derive all their nitrogen supply from the air were the first agencies and are still important factors in accumulating the nitrogen supply of the soil. Certain simple forms of plant

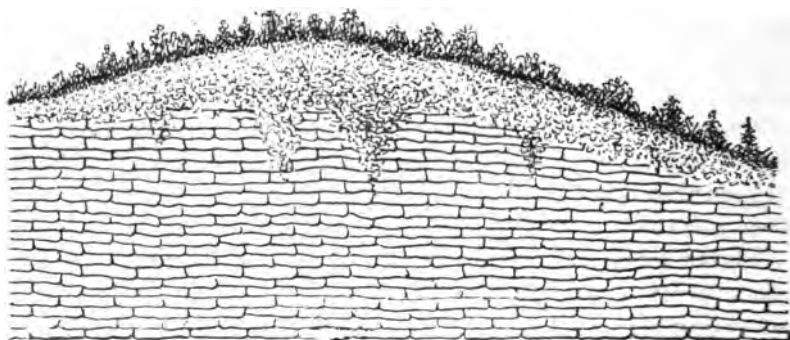


Diagram illustrating the formation of a soil on a limestone hill (after Vivian).

life, as lichens and mosses, it is believed, can also derive their nitrogen from the atmosphere. When, after death, a plant becomes a part of the soil, all the plant food it contained is returned. Food, once used by plants, is readily made available to succeeding crops through processes of decay and nitrification. The soil is thus made richer and more fertile. In this way growth gradually becomes more abundant. The plants upon decay give rise to "humus," the chief nitrogen containing body of the soil and from which the higher plants, through ammonification and nitrification, derive their necessary supply of nitrogen.

Legumes enrich soil with nitrogen. This particular class of plants to which the clovers, alfalfas, vetches, lupines, peas, and

beans belong, is able, through the agency of nodule forming bacteria growing on the roots, to derive nitrogen from the inexhaustible stores of the atmosphere. This peculiar property of leguminous plants is quite distinct from the requirements of all other farm crops, which acquire their nitrogen from the nitrogen compounds already in the soil. This fact is of the greatest importance to agriculture, for it is "Nature's principal method" of increasing the nitrogenous food in the soil. The nitrogenous compounds stored in such plants eventually become a part of the soil through their decay, thus furnishing food for other plants and increasing the fertility of the soil.

The constituents of soil. A popular and convenient classification of soil constituents is the following:

(1) *Sand*—mainly silica, but containing small fragments of feldspar, mica, and other minerals.

(2) *Clay*—mainly kaolin, but containing small fragments of silica, feldspar, etc.

(3) *Limestone*—finely divided calcium carbonate.

(4) *Humus*—the somewhat indefinite nitrogenous and carbonaceous material, brown or black in color and resulting from the decay of plants. A brief description of these materials will now be given.

Sand is of low specific heat and has the lowest water retaining power of all soil constituents. It is practically valueless as a plant food, except for the small amounts of potassium, calcium and iron contained in the mineral fragments mixed with the true sand. Its physical properties often have valuable effects upon the character of a soil, particularly with regard to friability, and its relation towards water and heat.

Clay in its pure form is free from plant food, but is usually well supplied with potash, because of the feldspar present. Common clay contains quartz and calcium carbonate (as in marls) in addition to feldspar. The true clay (kaolin) acts as a cement to the other mineral grains.

It is thought that even in the purest clay there is a small quan-

tity of aluminum silicate containing more water than the rest, to which the plasticity and tenacity of clay is due. If this constituent is fully swollen with water the clay is impervious and sticky, while if it is shrunken or coagulated the clay becomes more friable and less plastic. Calcium compounds are particularly effective in inducing such coagulation and it is to this cause that the improvement in texture of heavy clays by lime applications is due.

Lime stone. Calcium carbonate is present in the soil in a finely divided state distributed among the other constituents, but in addition there may be larger fragments which are classed with the "sand." The finely divided material is the one of importance. It furnishes plant food, for the plant must have calcium, but it also plays other important functions. It modifies the plasticity of clay in the manner described above and in addition neutralizes any acids accumulating in the soil. Acids are produced by the decay and fermentation of vegetable matter, and if allowed to accumulate, will render the soil unfit for maximum crop production. Such soils are spoken of as "sour" and can best be restored to fertility by the application of quick lime or ground limestone. Limestone performs another important function by acting as a basic material necessary for the process known as *nitrification*, to be explained later.

Limestone also serves an important function in those soils which have received applications of the commercial fertilizer, ammonium sulphate. It prevents the accumulation of sulphuric acid, which otherwise would make the soil sour, by its power to neutralize this acid. The neutral salt formed—calcium sulphate—partly runs off in the drainage water.

Humus is the brown or black organic matter of surface soil. It is the product formed by partial decay of organic matter and is the material that gives the rich black appearance to some soils. It is formed from the residue of plants previously grown on the soil or from added organic matter in farm manures or commercial fertilizers. It is a mixture of many ill-defined bodies. Besides

the nitrogen contained in it, there is always found in its ash, such plant food elements as phosphorus, potassium, iron and sodium, together with silicon and aluminum. These ash constituents are thought to be of considerable importance because they are apparently easily available to plants.

The humus of soils is of the greatest agricultural importance. It not only modifies its physical properties, but is the principal storehouse for nitrogen. A soil rich in humus is rich in nitrogen; a soil poor in humus is poor in nitrogen. The plant does not use it directly, but its nitrogen must first be converted by bacteria into water soluble forms, such as nitrates, before it is available. By the decay of humus the proportion of carbon dioxide in the soil water is increased and thus the solvent powers of the latter for plant food in the mineral portion of the soil are enhanced.

Virgin soils are comparatively rich in humus, but continuous cropping with no return to the soil of humus forming materials may result in its being decreased from one-third to one-half in a period of not more than fifteen years. The amount of humus in soils is variable, dependent upon such factors as climate and the previous soil treatment. In humid regions ordinary arable soils vary in humus content from 2 to 5 per cent. Swampy, peaty, and muck soils contain larger amounts. In a bog soil the per cent of humus may be as high as 30 per cent. In arid regions the amount of humus in the soil is normally less than found in our humid regions, the amount rarely exceeding 1 per cent.

These materials described above have great influence upon both the physical and chemical properties of soils. The important physical properties of the constituents themselves are shown in the table on page 48.

The explanation of the terms used in the table are as follows: Specific gravity is the weight of any volume of the solid material compared with that of an equal volume of water. Specific heat (equal weight) is the ratio of the amount of heat necessary to raise the temperature of a certain quantity of a

substance compared with that required to raise an equal weight of water through the same range of temperature. Specific heat (equal volume) is the relative amounts of heat required to raise equal volumes of the material and of water through a given range of temperature.

Physical Properties of Soil Constituents.

	Specific Gravity	Specific Heat Equal Weight	Specific Heat Equal Volume	Water held by 100 parts by weight of substance
Water.....	1.00	1.000	1.000	.....
Sand.....	2.62	.189	.499	25
Clay.....	2.50	.233	.568	70
Limestone.....	2.60	.206	.561	85
Humus.....	1.30	.477	.587	181

From the above table we see that the same quantity of heat will raise 1 pound of water and 5 pounds of limestone or sand to about the same temperature, or if we consider only the solid constituents of soil, the same amount of heat will raise 3 pounds of humus and 8 pounds of sand to the same temperature.

Relation to heat. The sources of heat to a soil are the sun and chemical changes within the soil. The chemical oxidation of organic matter in the soil will slightly raise the temperature, but by radiation are largely influenced by weather conditions. Extremes of heat and cold occur with a clear sky and dry air. In a cloudy, moist climate, the variations in temperature are comparatively small. At mid-day the power of the sun's rays is at depth of 1 foot, the average temperature of the soil, after a lapse of 20 days was 2.3° higher than that of unmanured soil. During the next 5 days the excess of temperature was only 0.8°. Chemical action is at its height during the summer months.

The amount of heat received from the sun and the amount lost the effect is generally slight. In an experiment at Tokio, Japan,

where 40 tons of manure were incorporated with the soil to a)
its maximum. They then pass through a minimum thickness of
the atmosphere. At sunrise they are weakened by diffusion over
a wide area and in addition are diminished in intensity by ex-
cessive atmospheric absorption. The difference in the angle of
incidence of the sun's rays is the principal cause of the difference
between a tropical climate and that of Wisconsin. The slopes on
our own fields often offer examples of such effects. It is on a
slope facing south that the soil will reach its highest temperature
during sunshine.

A dark colored soil becomes warmer in the sun's rays than a
light colored one, a larger proportion of the sun's energy being
absorbed and converted into heat. No difference will be observed
on cloudy days. At night all soils will cool to the same point.

When a soil is freely exposed to the sky the temperature at the
surface will reach a higher maximum and fall to a lower min-
imum than the air above it. Schuebler found that the freely ex-
posed soil in his garden at Tuebingen, Germany, averaged at
one-twelfth inch below the surface, shortly after noon and in per-
fectly clear weather, about 120° Fahr. for every month from
April to September inclusive, and in July reached 146°; this
latter temperature was 65° above that of the air taken at the
same time.

With dry soils, including only hygroscopic water, about 3 cubic
feet would be heated by the sun to the same degree as one cubic
foot of water. In this condition there is little difference between
different soils; a dry peat will consume the least heat and a dry
clay the most. When, however, soils become wet great differ-
ences appear. In a freshly drained condition, a coarse gravel or
sand will warm to a greater depth, while soils retaining more
water will warm to a less depth. The specific heat of wet peat
does not differ greatly from that of its own bulk of water.

The depth to which a soil will be heated depends, however,
partly on the conductive power of its constituents. Sand has the
greatest power of conducting heat of any soil constituent. Air,

present in the soil, is the worst conductor. A dry soil is thus a very poor conductor of heat. Consolidation improves the conductivity. Wetting the soil doubles the conductivity of sand, limestone, or clay by displacing the air. We see then, that a dry, loose soil will get very hot at the surface when exposed to the sun, but the heat will penetrate to a slight depth. This explains why gravelly soils are best suited for early spring crops.

Presence or absence of much water is the important factor which chiefly determines the cold or warm character of a soil. A still more potent reason for the coldness of wet soils, is, however, the loss of heat during evaporation. When a pint of water is removed by evaporation from 97 pints, the 96 remaining pints will have fallen 10° Fahr. in temperature unless this amount of heat has been supplied from some external source. Undrained meadows and heavy clays consequently are cold soils because much of the sun's heat is, in these cases, consumed in evaporating water. Parks found that an undrained peat bog 30 feet deep, had a temperature of 46° when measured below a distance of 1 foot from the surface. In the middle of June he found the temperature 47° at 7 inches below the surface, while the drained portion had a temperature of 66° at this depth, and a temperature of 50° at 2 feet below the surface. Draining is the only cure for a cold, wet soil.

The temperature of the subsoil is practically constant throughout the year at a certain distance from the surface. Observations at Greenwich Observatory, England, in a well drained gravel, showed that the variations of day and night are slightly felt at 3 feet from the surface. At 25½ feet the maximum temperature usually occurs in the latter part of November and the minimum in the first week in June. The difference between the two is about 3°. These observations make it clear that the soil and subsoil are generally warmer than the air in autumn and cooler than the air in spring.

Tenacity of soil. The tenacity of a heavy soil is due to the fine silt and clay. The coarser elements of a soil, such as a fine

sand, exhibit little cohesion. Clay owes its cementing power it is believed, to the presence of a small quantity of a hydrated colloid (jelly-like) body, which according to Schloesing rarely exceeds 1.5 per cent of the clay. The remainder of the clay is composed of extremely fine, solid particles. In the purest natural clays, all the constituents have the same general chemical composition, that is, they are hydrated silicates of aluminum; but in soils the non-colloid constituents of the clay may be of a very various nature. In brick clay this material is quartz sand; in marl it is limestone.

The condition of clay soils depends much on whether the clay is coagulated or not. When the clay is uncoagulated, the soil is sticky, impervious to water, and cannot be reduced to a fine tilth. When a clay is coagulated the soil has a granular structure, is pervious to water, and can be reduced to powder. It is coagulated by lime and by many salts, and especially by salts of calcium. Colloid clay will remain permanently suspended in distilled water. It is precipitated by the addition of a small quantity of a calcium salt. An application of lime to clay soils is well known to be extremely effective in diminishing their tenacity, rendering them pervious to water, and more easy of tillage.

In cultivated sandy soils humates are often of great value as cementing materials; these, like true clay, are colloid bodies. Schloesing found that 1 per cent of a humate, as calcium humate, was as effective as a cement for sand as 11 per cent of clay. Humates, however, will lose their cementing power on drying, while clay will not. The improvement of the texture of sandy soils by the continued use of farm yard manure, or by the plowing under of green crops, is a fact familiar to the farmer. While applications of humus forming materials, as the above, increase the coherence of sand, they have an opposite effect on clay, and are the most effectual means at the disposal of the farmer for lightening a heavy soil. Lime will also tend to increase the coherence of sand.

Relation to water. We have learned that a good soil consists of solid particles of fairly uniform size. The spaces between these particles constitute about 40 per cent of the volume. If the particles are a mixture of large and small, as for example gravel and sand, the volume of these spaces is much reduced. On the other hand if the particles are themselves porous, as in the case of chalk, loam, and especially humus, then the volume of the spaces is increased. It is this volume of the inter-spaces which determines the amount of water which a soil will contain when perfectly saturated, or the amount of air which it will contain when dry.

Humus increases the capacity for a soil to absorb and retain water and consequently a crop grown on a soil containing a fair amount of humus is less likely to suffer from drought. The following table illustrates this point. It gives the amount of water held by 1 cubic foot of different varieties of soil;

<i>Kind of Soil</i>	<i>Lbs. of water in 1 cubic foot</i>
Sand	27.3
Sandy Clay.....	38.8
Loam	41.4
Humus.....	50.1

Farm crops will not grow in a soil permanently saturated with water and from which air, consequently, is excluded; the best growth is obtained from soils one-half or two-thirds saturated. The surface of a soil is seldom saturated, except immediately after a heavy rain; it is the quantity of water which a soil will retain when fully drained which determines its capacity for supplying a crop with water. The amount of water permanently retained by a soil does not depend upon the volume of the inter-spaces, but upon the extent of internal surface, the water being held by adhesion as a film on the surface of the particles. The smaller, therefore, the particles of a soil, or the more porous, the greater is the amount of water retained. Two samples of pow-

dered quartz, one coarse, the other very fine, will hold when saturated, more than 40 per cent of their volume as water. But when drained, the coarse sand will retain about 7 per cent while the fine quartz holds 44.6 per cent of water. The latter will loose, in fact, no water by drainage.

Gravels and coarse sand retain the least water when drained. As the particles become smaller, the retention of water increases. Colloids, jelly-like bodies, as clay and humus, increase the power of retaining water, as such bodies swell up when wetted and hold the water in jelly-like substances. The addition of humus to soils is one of the best ways of increasing their water retaining capacity.

Water from below may supply a surface soil if a saturated sub-soil exists at a moderate distance. Such water is said to be raised by capillary action, which simply means that the surfaces of the soil particles exert an attraction for water. The finer the particles and the closer they are packed, the greater the height to which water will be carried by capillary action. When the distance it has to travel increases, the quantity reaching the surface diminishes. When the fineness of the particles exceeds a certain point the quantity of water raised also diminishes. It is not always the soil with the finest particles that brings most water to the surface. There is a certain degree of fineness of soil particles that acts most effectively. Capillary action is seldom able to maintain a sufficient water supply at the surface. In Wisconsin every few years crops suffer from drought, although a permanent water supply exists several feet below the surface. Capillary action is most effective in the case of silty soils; such soils were deposited from running water and consist of very uniform particles, but without any true clay. Some western soils, which are capable of growing wheat with a winter rainfall of 10 to 12 inches and a continuous summer drought of three months' duration, are deep, fine grained, and uniform, with practically no particles of the fineness of clay to check the upward lift of capillarity.

The evaporation from a saturated soil is greater than from a water surface and as the soil dries the rate of evaporation rapidly diminishes. The average annual evaporation from a bare loam at Madison, Wisconsin, is about fifteen inches. While soils of various character evaporate equal amounts while saturated, they exhibit great differences as drying proceeds. A soil of coarse particles and loose texture dries quickest and to the greatest depth. Consequently it appears to be good practice to avoid deep tillage in early summer, if land is intended to carry a crop.

Evaporation from the soil is diminished by protection from sun and wind. Economy of water is best effected by mulching with straw. Keeping the surface stirred to a depth of an inch or two, thus providing a mulching of loose dry soil, is an excellent practice and forms a fundamental part of successful cultivation in dry climates.

The greatest evaporation of water takes place from the soil when it grows a crop. The water in a soil growing barley and in an adjacent bare fallow was determined at Rothamsted, England, at the end of June during the drought of 1870. It was found that down to 54 inches below the surface the barley soil contained 9 inches less water than the fallow soil. The injurious effect of weeds in the summer time is largely due to their robbing the soil of water.

With dry soils the farmer should aim to increase the amount of humus. Crops should be sown early and the land kept solid; very shallow summer cultivation should be resorted to. Such land may possess distinct advantages. It furnishes the earliest crops to market gardeners, the soil being easily warmed. A little rain will wet it to a considerable depth and the whole of the water it contains is available to plants.

A soil, when drained, is seldom too wet because of its power to retain water. The trouble is more often due to want of drainage; the remedy for such a soil is deep tillage and draining. Applications of lime or an increase in the humus content may be

an effective means of rendering the surface soil more pervious to water.

The wettest soil does not always supply the largest amount of water to a crop. A peaty soil holds most water, but it is held so firmly by the colloid matter as to be unavailable to plants. A stiff clay fails in a drought as the water in this class of soils is also firmly held and moves with difficulty. Soils composed of silt or extremely fine sand are those which yield water most effectually to a growing crop.

Chemical changes occurring in soils. The chemical changes going on in soil are numerous and complex. The mineral matter is subjected to the same influences as led to its breaking down in the formation of soil from the original rock. These changes are, however, hastened because of the great quantity of carbon dioxide produced by the decay of organic matter. Fragments of feldspar are decomposed with formation of silicic acid, potassium carbonate and kaolin or clay. The clay remains behind, but the silicic acid and potassium carbonate may in part be dissolved and either carried away in the drainage, or may be absorbed by the roots of plants or by some of the absorptive constituents of soils. Calcium carbonate or limestone is dissolved by water containing carbon dioxide, which is true of all soil waters, and is in part carried away in the drain or absorbed by certain soil constituents.

Calcium phosphate, as it exists in minerals, is nearly insoluble in water, but through the action of the soil water containing carbon dioxide in solution, it is changed to more soluble forms and therefore becomes available to plants. In contact with certain forms of iron and aluminum in the soil the soluble calcium phosphates may be changed to iron and aluminum phosphates and held back in the soil in finely divided condition, and though then quite insoluble in water, may still be dissolved by the acid juices of the plant's roots.

Absorption of soluble plant food by soils. If the plant food made soluble by the chemical changes occurring in soils were not

retained by its absorptive power the depletion of fertility would go on at a much more rapid rate than it actually does. Most soils contain substances, which have the power of uniting with potassium, ammonium, and to a less extent with calcium compounds and with phosphates, converting them into insoluble forms. If a solution containing phosphoric acid, potash or ammonia is poured upon a sufficiently large quantity of fertile soil, the water which filters through will be found nearly destitute of these substances. This retentive power of a soil is of the greatest agricultural value as it enables it to maintain its fertility when washed by rain and permits of the economic use of many soluble manures. Ferric oxide, a common ingredient of soil and one to which the red color of many soils is due, will retain and fix any soluble phosphate. When a solution of phosphate of calcium in carbon dioxide is placed in contact with an excess of hydrated ferric oxide, the phosphoric acid is gradually absorbed and the calcium left in solution as a carbonate. Hydrated alumina acts in the same way. Ferric oxide and alumina have also a retentive power for ammonia, potash and other bases, but the compounds formed are more or less decomposed by water.

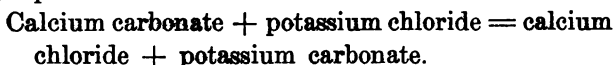
The permanent retentive power of soils for potash and other bases is chiefly due to the hydrous double silicates.

Humus has a great absorptive power for ammonia. It also retains other bases with which it can form insoluble compounds.

Magnesia, lime and soda are retained by the soil, but in a less powerful manner than are potash and ammonia. When a solution of a salt of potassium or ammonium is placed in contact with a fertile soil, lime will come into solution and take the place of the potash or ammonia, which is by preference, absorbed.

Soils destitute of lime retain very little potash or ammonia when these are applied as salts of powerful acids, as for instance, as chlorides, nitrates, or sulphates. When carbonate of calcium is present the potassium or ammonium salt is decomposed, the base is retained by the soil, while the acid escapes into the drain-

age water united with calcium. This is illustrated in the following equation:



The addition of marl or limestone may thus greatly increase the retentive power of a soil for bases. The bases absorbed by the soil may be slowly removed by the action of water. This of course occurs to the least degree in a soil that has absorbed little or has been already washed, and is greatest in a soil that has been heavily manured.

The permanent fertility of a soil is closely connected with its power of retaining plant food. In soils containing clay, only traces of phosphoric acid, ammonia or potash are ever found in the drainage water. Sandy soils, from their smaller chemical retentive power and free drainage, are of less natural fertility and much more dependent on immediate supplies of plant food.

There can be little doubt that the active plant food contained in a soil, which is capable of being taken up by roots, exists either in solution or in the states of combination just referred to—that is, in union with ferric oxide, hydrous silicates or humus. Different crops have very different powers of attacking these various forms of plant food.

Nitrification. Perhaps the most important reactions going on in a soil are those connected with the decay of organic matter and the changes in the state of combination of the nitrogen. The organic matter is continually being oxidized, the carbon being mainly converted into carbon dioxide. The material from which the nitrogenous matter of soils is derived contains always a large proportion of carbon. In the roots and stubble of cereal crops the relation of nitrogen to carbon is about 1:43; in those of leguminous crops 1:23; in moderately rotted farm manure 1:18. In an aerated soil these materials are oxidized by the action of various organisms (worms, fungi, and bacteria) and large quantities of carbon dioxide produced. As a result of this loss of carbon, we find that the surface soil of a pasture (roots removed)

will contain about 1 part of nitrogen to 13 of carbon; the surface soil of an arable field 1:10, and a clay soil 1:6. These figures represent the proportion of nitrogen to carbon in the commonest forms of humus matter. Humus represents merely a stage in the decomposition of organic matter; in the end the whole of the carbon, hydrogen and nitrogen appear as carbon dioxide, water and ammonia or nitrates.

The nitrogen contained in humus is not in a condition to serve as food for ordinary crops. The gradual decomposition of soil humus is consequently generally essential to fertility. This change in the humus is brought about by fungi and bacteria, which convert the nitrogen of organic matter into ammonia and nitrates, forms which are soluble in water and available to the plant. The final *nitrification* of ammonia is performed by two species of bacteria, one of which produces nitrites, which the other changes into nitrates. Fresh plant residues are more easily nitrified than old humus matter, but nitrification does not begin until the earlier stages of decomposition have occurred.

The nitrifying organisms occur most abundantly in the surface soil; the depth to which their action extends depends on the porosity of the soil. In experiments at Rothamsted, England, on a clay subsoil, it was found that the organisms did not always occur in samples of the soil taken at more than 3 feet below the surface.

Nitrification only takes place in a moist soil and one sufficiently porous to admit air. It is always necessary that some base should be present with which the nitric acid formed may combine. This condition is usually fulfilled by the presence of carbonate of lime. Lack of oxygen and an acid condition of the soil are both unfavorable to the growth of nitrifying organisms. This gives us a rational explanation of the advantages of thorough tillage which aerates the soil and of the maintenance of non-acid soils by the application of lime. Nitrification is most active in the summer season; it ceases near the freezing point. The nitrifying organisms may be killed by severe drought.

The oxidation of humus not only makes the nitrogen, which it contains, available to plants, but it also liberates the ash constituents combined with the humus and enables them to take part again in the nourishment of the growing crop.

Oxidation is most active in soils under tillage. In arable land the production of available plant food is at its maximum and so is also the waste by drainage. The nitrogenous humus matter of tilled land is maintained only when the new supply from crop residues and organic manures is equal to the amount annually oxidized. In an untilled pasture or forest soil, on the other hand, a considerable accumulation of organic matter may take place, the annual residue of dead leaves and roots being often in excess of the amount oxidized.

In a peat bog oxidation is further checked by the high water level, which excludes air from the soil; under such conditions an unlimited accumulation of organic matter may take place if plants capable of growing under these circumstances are present.

Denitrification—When a soil is not in an aerated condition, but has the spaces between the particles filled with water, the nitrates present are destroyed by certain kinds of bacteria, the oxygen of the nitrate combining with carbon to form carbon dioxide, while the nitrogen is set free and returned to the air in its elemental condition. If a soil be consolidated, waterlogged or highly charged with oxidizable carbonaceous matter, the conditions become favorable for denitrification. Conditions favorable to nitrification, such as a plentiful supply of oxygen and absence of acidity, are those unfavorable to denitrification, so that the farmer in producing proper conditions for the former desirable process is at the same time preventing the injurious denitrification. The application of very large dressings of manure, along with nitrate of soda, sometimes causes a considerable loss of nitrogen from this process of denitrification.

Fixation of atmospheric nitrogen in soils. Besides the organisms associated with leguminous plants and which assimilate atmospheric nitrogen freely when in union with the roots of the

host plant, there are bacteria in the soil which use free nitrogen, but which do not grow in union with the higher plants. These bacteria are found in most soils and are said to possess this power when the supply of carbonaceous matter in the soil is plentiful. Indeed, some years ago, such organisms under the name of "alinite" were prepared for sale, but the success attending their use was doubtful and their manufacture has ceased.

It is thought that the fertility and richness in nitrogen of forest or prairie soil is largely due to the activity of such organisms, which would find suitable conditions for growth in the large quantity of organic carbonaceous matter contained in such soils. At present it is impossible to say whether the nitrogen added to the soil in this way is of any considerable amount.

Gases in a soil. The spaces between the particles of soil, besides containing a certain amount of moisture, are usually occupied by air. Because of the chemical changes going on in the soil this air becomes robbed of its oxygen, and enriched with carbon dioxide. This air is not stagnant but undergoes constant renewal by diffusion from the air above.

The gases drawn from the soil at different times will be found to vary in composition; the oxygen may be anywhere from 10 to 20 per cent, the carbon dioxide from 1 to 10 per cent, while the nitrogen usually differs very little in amount from that in the atmosphere, that is, about 78 per cent. The amount of carbon dioxide is greater and of oxygen less during the summer and autumn than in the winter or spring. The higher temperature in the soil during summer and autumn favors chemical decomposition, with greater production of carbon dioxide.

Tillage and drainage. The operations of tillage and drainage serve in many important ways to make the conditions for plant life more favorable and to increase the amount of plant food which is at the disposal of the crop.

By tillage the surface soil is pulverized and brought into a loose, open condition. Large lumps are broken into small particles and the fine tilth thus obtained, allows a rapid extension

of the delicate root fibres and consequently greater room for root growth. It increases the surface to which the roots are exposed and necessarily gives the developing plant a larger feeding area.

Tillage hastens chemical changes in the soil by bringing together particles which have not before been in contact. Particles with different chemical properties are thus enabled to act upon each other.

The changes induced by freezing and thawing may also be greatly increased by proper tillage. Fall plowing exposes the large lumps to the influence of the weather during the winter. This disintegrates the clods and improves some classes of soils in a remarkable manner. It also tends to save the moisture, as the loose ground turned up by the plow prevents loss of water by evaporation. The broken uneven surface also favors a greater absorption by the soil of the winter rain or snow. In an experiment at the Wisconsin Station, a plot plowed in the fall contained 1.15 acre inches more water than an adjacent plot not so plowed. It must be remembered that fall plowing may not always be the best practice, as hard soils, low in humus, may be badly puddled if fall plowed. Plowing the ground very early in the spring is a rational practice, for there is no other season when tillage is so effective in conserving the soil moisture. Experiments indicate that in soils where such practice has been followed, the moisture content will be greater than in those unplowed. Judgment must be exercised, however, in the choice of time in order that no injury to the texture may follow.

By the action of the plow, the residues of crops, weeds and manures are buried, and incorporated with the soil. The deep tillage of heavy land allows rain to penetrate it and establishes the drainage of the surface soil, and increases the temperature.

A shallow surface tillage preserves the moisture of the soil in time of drought. It lessens the evaporation from the surface by breaking the capillary connection with the store of water below the surface. After a rain this will be again established and the cultivation should be repeated as soon as possible. Such a

surface layer of dry soil is called an "earth mulch" and serves the same purpose as a covering of straw or like material.

Another important result of tillage is that the soil is thoroughly exposed to the influence of the air. The nitrification processes are greatly facilitated, with the production of nitrates and carbon dioxide. The disintegration and solution of mineral particles will take place from the mechanical and chemical actions brought into play. It will also prevent the formation of such compounds as sulphide of iron, known to be injurious to vegetation. Oxygen is also necessary for the germination of seeds, and the aeration of soils by tillage is necessary for this important start in the plant's development.

By means of tile drainage the many chemical reactions going on in a soil are carried down to a greater or less extent into the subsoil; for as the water level is lowered the air enters from above to fill the spaces in the soil. By drainage, the depth to which the roots penetrate, and consequently the extent of their feeding ground, is increased. This helps them to withstand drought. They will not be so easily affected by the extreme drying of the surface of the soil that takes place in times of little rainfall. Roots will not grow in the absence of oxygen and will rot as soon as they reach a permanent water level.

In a water-logged soil denitrification is active and nitrates present are destroyed, a part of the nitrogen being evolved as elemental nitrogen and returned to the atmosphere. The soil may in this way, suffer a considerable loss of plant food by lack of drainage.

Losses caused by drainage. The water draining from land always carries with it dissolved matter. The substances chiefly removed by the water will be calcium carbonate, and the nitrates, chlorides and sulphates of calcium and sodium. When heavy rain falls these substances are washed into the subsoil and partly escape by the nearest outfall into the springs, brooks and rivers. The loss of nitrates during a wet season may be very consider-

able. The loss is greatest from uncropped soil for several reasons:

- (1) Because of the greater amount of drainage.
- (2) Because no absorption of nitrates by the roots of plants takes place.



Showing the dangerous practice of allowing soils to remain bare and exposed to the washing of rains (after Vivian).

- (3) Because the land, when free from crops, dries more slowly allowing nitrification to proceed for a longer time.

The average loss of nitrogen as nitrates from uncropped soil at Rothamsted, England, for 20 years, was 33.8 pounds per acre which is equal to 216 pounds of commercial nitrate of soda. The

loss will vary greatly with the nature of the soil. When the land is under crop this loss of nitrates by drainage is greatly reduced, these being constantly taken up by the roots and employed as plant food. In an experiment at Grignon, France, the yearly loss of nitrogen per acre on a soil bearing rye grass was but 2.3 pounds.

The losses of calcium carbonate vary considerably, dependent upon the nature of the soil. From soils of igneous origin its amount has been estimated at 500 pounds per acre per year, while from limestone soils the loss has been estimated at as much as 2700 pounds per acre. The amount lost is increased when ammonium compounds are used as fertilizer.

The loss of phosphoric acid is probably very small, except in the case of peaty soils, which though often very deficient in this constituent generally lose much in the drainage. This is probably due to the presence of vegetable acids and carbon dioxide produced by the decay of organic matter, which would intensify the solvent action of water. German experiments report an annual loss per acre of from about 8 pounds for clay soils to 19.6 pounds for peaty soils.

The loss of potash is variable, but small in amount. From experiments at Rothamsted, the annual losses in potash per acre were found to vary from 3 to 12 pounds. The losses of sulphur by drainage from soils may be considerable. At Rothamsted it was found that about 50 pounds per acre per year of sulphur, calculated as sulphur trioxide, escaped into the drainage water.

Highly manured land will sustain larger absolute losses of plant food than lands in an average state of fertility.

Soil as a source of plant food. The proportion of plant food present in soils is very small even when the soil is extremely fertile, the bulk of the soil serving as a support for the plant and as a sponge to hold the water. Many chemical analyses of soils have been made and these show a considerable variation in the composition of soil. A good arable loam may contain 0.15 per cent of total nitrogen, 0.15 per cent of total phosphoric acid,

0.10 per cent of total sulphur trioxide, and 0.2 per cent of potash and 0.5 per cent of lime, soluble in hydrochloric acid. Much larger quantities may, of course, occasionally be present. Plant food is not equally distributed throughout a soil. If a soil is separated by sifting into finer and coarser particles, it will be found that the finer particles are much the richer in plant food.

The weight of soil on an acre of land is so large that even small proportions of plant food may amount to very considerable quantities. An arable loam to the depth of 1 foot will weigh, when perfectly dry, about 4,000,000 pounds. A pasture soil will be lighter, the first foot weighing when dried with the roots removed about 3,000,000 pounds. If such soils therefore contain, when dry, 0.10 per cent of nitrogen, phosphoric acid, potash or sulphur trioxide, the quantity of each in 1 foot of soil will be from 3,000 to 4,000 pounds per acre.

The following table, partly taken from Vivian, gives the approximate amounts of nitrogen, phosphoric acid, potash and sulphur trioxide in the first foot of typical sandy loam, clay loam and clay soils:

Amount of Plant Food per Acre in the Surface Foot.

Kind of Soil	Nitrogen lbs. per acre	Phosphoric acid lbs. per acre	Potash lbs. per acre	Sulphur trioxide lbs. per acre
Sandy loam.....	3,736	7,326	28,669	4,000 (assumed)
Clay loam.....	4,789	4,935	44,827	4,000 (assumed)
Clay	3,250	5,600	12,600	4,000 (assumed)

The amount of plant food present in the soil is surprising, in view of the fact that it is often difficult to maintain a satisfactory yield of crops. An acre of soil may contain many thousand pounds of phosphoric acid or of nitrogen and yet be in poor condition; while an application of commercial fertilizer supplying 50 pounds of readily available phosphoric acid in the form of

super-phosphate or nitrogen as nitrate of sodium, may greatly increase its productiveness. If we compare the above table with the table in the appendix, showing the amount of plant food removed by various farm crops, it will be seen that the clay loam soils show the presence of sufficient nitrogen for 95 crops of wheat yielding 30 bushels per acre; phosphoric acid for 233 crops; sulphur trioxide for 254 crops; and potash enough to supply 1555 such crops. There is, in addition, nearly as much phosphoric acid and potash in the second and third foot, so that as far as the latter substance is concerned, the supply seems almost inexhaustible. The other two substances, nitrogen and phosphoric acid, and probably a third, sulphur, must be considered as limited in quantity in many of our soils. In peat soils, potash may also be very low.

While chemical analysis will often disclose a large total amount of plant food sufficient for many crops, nevertheless experience has demonstrated that long before the theoretical number of crops have been produced the yield will have decreased so materially as to become unprofitable.

Available plant food. Chemical analysis gives the total amount of nitrogen, phosphoric acid and potash in a soil, but it does not indicate what part of these materials is available to the plant. It takes an inventory of our stock on hand but does not measure the crop-producing power of the soil. A large proportion of this plant food is locked up in insoluble compounds, in which form the plant is unable to use it. Food can be taken up by the roots of plants only when in solution or in a condition capable of being dissolved by contact with the acid sap of the root hairs.

The agencies operative in the soil and which we have already considered are continually changing these insoluble compounds to forms available to the plant; most of the soil ingredients are in an insoluble form and this fact is really of the greatest importance, for if it were not so soils would then lose fertility by heavy rains. The unavailable or "potential" plant food is grad-

ually being made available, but not with sufficient rapidity to replace that removed from the field at harvest, and the yield of crop produced will be limited by the element of this available plant food present in least quantity.

Continuous cropping of the soil, with the removal of everything from the field results in the exhaustion of the plant food which has been rendered available during the past ages.

CHAPTER IV

NATURAL WATERS

Pure Water—or the substance made of the two elements hydrogen and oxygen—practically never occurs in Nature. Because of its great solvent properties, water always dissolves certain quantities of every substance with which it comes in contact.

The purest form of natural water is rain; however, rain water is never pure, but contains varying quantities of dissolved matter. The quantity of dissolved substances will depend upon the locality in which the rain fell. In cities and in the neighborhood of factories this will be larger than in the open country. The character of the substances in solution will also depend upon the locality. The rain water in cities, besides containing compounds of nitrogen, as ammonium nitrate, may be acid. This is due to dissolved sulphuric acid, which had its origin in the sulphur dioxide produced from burning coal. In addition to these substances rain water contains dissolved gases.

When it reaches the earth the water at once begins to dissolve the substances upon which it falls. In regions where the surface is composed of hard, igneous rocks, the quantity of material dissolved is small, while on lime-stone soils the amount of calcium carbonate that goes into solution is large.

The water which drains away from a soil, partly finds its way into the nearest creek, then to a stream or river, and finally to the sea. Another portion sinks into the earth, until stopped by some impervious layer of rock—as shale or hard pan—when it accumulates and eventually finds an outlet at some lower level in the form of a spring.

The industrially important waters may be classed as follows:

1. *Rain water.*
2. *Ground waters* furnished by
 - (a) Springs,

(b) Shallow wells (penetrating but one geological stratum),

(c) Deep wells (passing through more than one such stratum).

3. *Surface waters* consisting of

(a) Flowing waters (streams).

(b) Still water (ponds, lakes, etc.)

4. *Sea water*.

Rain water. The composition and character of this has already been described in Chapter II. It contains very little mineral matter and is described as "soft" for this very reason. If it could be collected without further contamination it would be by far the best for most purposes. The acidity of the rain in districts where much coal is burned is of great importance as affecting the growth of plants, particularly grasses and certain trees. In addition to its direct injurious effect upon the foliage, it exerts a deleterious action upon the soil, tending to remove the calcium carbonate or other basic material and to promote "sourness," a condition which is very unfavorable to the growth of most useful plants. It is known that grass lands under such circumstances become almost sterile, the last plants to succumb to the unfavorable conditions being usually the "sorrel" or "sweet dock."

Ground Water. The water issuing from springs varies greatly in the amount and nature of the dissolved matter which it contains. If this be small, and not possessed of strong odor or taste, the water is described as fresh water; but if a large quantity of dissolved matter be present, or if the water possesses pronounced taste, odor, or medicinal properties, it is known as a mineral water.

Many spring waters contain the following substances, but in varying amounts:

1. Calcium and magnesium carbonates dissolved in excess of carbon dioxide.

2. Calcium or magnesium sulphate.

3. Sodium or potassium chloride.
4. Alkaline silicates.
5. Dissolved gases as oxygen, nitrogen and especially carbon dioxide.

Calcium and magnesium carbonates are almost insoluble in water, but if the water contains carbon dioxide, the readily soluble bi-carbonates of calcium and magnesium are formed.

Such action occurs in all lime-stone districts and the removal of the rock by solution gives rise to the caves and underground water courses so common in such localities. The great Mammoth Cave of Kentucky and Perry Cave of Northern Ohio are illustrations of such action.

When such water is boiled the bi-carbonates are decomposed, losing part of their carbon dioxide, and normal carbonates are again formed. These are insoluble and consequently appear as a precipitate. In many cases the precipitated calcium or magnesium carbonate forms a firmly adherent coating or crust upon the bottom or sides of the kettle or boiler.

Calcium and magnesium sulphates are soluble in water, the former to the extent of about 1.7 grams per liter (1 oz. in 18 quarts of water). Waters containing calcium or magnesium compounds are known as "hard" waters, and have a peculiar and well known action on soap. The latter is essentially a sodium salt of the fatty acids, as stearic, palmitic and oleic acids. These acids are the constituents of our principal fats and it is the common practice of every good housewife to save the fat "scraps" for the home soap-making. The sodium and potassium salts of the fatty acids are soluble in water, but the calcium and magnesium salts are insoluble. For water to form a lather with soap or properly exercise its cleansing power, it is necessary that the water should contain in solution some of the sodium or potassium salts of the fatty acids. When a small quantity of soap is dissolved in hard water, the calcium or magnesium present in the water displaces the sodium or potassium and gives a curdy, flocculent precipitate of the calcium or magnesium salts of the

fatty acids. The dissolved soap is thus removed and more has to be dissolved before the proper cleansing action can be exerted. Hence hard waters are unsuitable for domestic, especially for laundry, purposes; they involve the consumption of large quantities of soap and contaminate the washed articles with the precipitated "lime" or "magnesia soap."

Hard waters are also unsuitable for steam-raising, since the deposit of calcium carbonate or calcium sulphate (boiler scale) upon the boiler plates greatly increases the consumption of fuel required for the production of a certain quantity of steam. Calcium carbonate alone forms a porous and non-adherent scale, which is easily removed by "blowing off" the boiler. Calcium sulphate forms a hard compact scale, which adheres very firmly.

A distinction is often made between waters, which contain their calcium and magnesium as bi-carbonates and those in which the salts present are as sulphates. The former are known as "temporarily" the latter as "permanently" hard waters. By the removal of the excess of carbon dioxide from the former the calcium and magnesium carbonates are precipitated, while with the latter the salts are in solution and cannot be precipitated by the simple removal of carbon dioxide.

The usual method of procedure to effect the softening of temporarily hard water is to add "milk of lime" in sufficient quantity to combine with the free carbon dioxide and that present as bi-carbonates. The precipitate formed will be found to contain the calcium and magnesium carbonates originally present, together with that formed from the added lime. On standing, the precipitate settles out and the clear liquid is then almost free from calcium and magnesium and is "soft." The milk of lime should be added slowly and gradually and care be taken that no great excess is used. Water so treated is much improved both for washing and for steam-raising purposes. The "milk of lime" is made by treating a quantity of quick lime with water and after thoroughly stirring, the "milk" is then mixed with the water to be purified.

Another method is to boil the water either in the open air or in special heaters. This decomposes the bi-carbonates, drives out the excess of carbon dioxide and the normal carbonates of magnesium and calcium settle out as precipitates.

Permanent hardness is less easily remedied, for in every case the treatment of the water leaves in solution some substance more or less deleterious. Sodium carbonate and barium chloride are the materials in common use. A recent suggestion calls for the use of sodium bi-chromate within the boiler, as a corrective for both temporary and permanent hardness. It is claimed that the calcium and magnesium chromates precipitate in the boiler as a loose, non-adherent mass, which is removed by "blowing off" daily. It is further claimed that the free chromic acid does not attack the boiler iron. Much care is necessary in order to avoid an excess of any chemical added. As a rule the water should be treated before it goes into the boiler. But if the scale-forming material does not exceed 150 parts per million, the purification may be done in the boiler itself, followed by daily "blowing off."

A great many proprietary "anti-scale" preparations are sold, many of which are of no particular value. Most of them are to be used inside the boilers. Some are supposed to act chemically on the impurities and others are mechanical, preventing the adherence of scale. The former usually contain soda-ash, caustic soda, barium hydroxide, or sodium phosphate. Tannin in the form of sodium tannate, is sometimes employed, by which the calcium and magnesium are separated as tannates.

In a drinking water the presence of calcium compounds, except perhaps in excessive amounts, is not objectionable. Indeed, it is often advantageous, furnishing a portion of the lime necessary for the building up of the hard parts, such as bones or shells, of the animal. Moreover, in many cases water is delivered through lead pipes and soft waters, especially if they contain vegetable acids, as for example peaty waters, attack and dissolve the lead, and often to such an extent as to cause lead poisoning in those

who drink them. The presence of calcium sulphate renders water incapable of this dangerous action upon the lead. In the presence of calcium sulphate the metal becomes coated with a film of the very insoluble lead sulphate, which protects it from further contact with the water.

Organic matter. Of greater importance than the mineral matter in drinking water, is the amount and nature of the organic matter. This in itself is comparatively harmless. Its importance lies in the influence it may have upon the kinds of micro-organisms which accompany it. Animal excreta is the most dangerous contamination, since the micro-organisms which cause various diseases, as for example, typhoid, cholera, etc., are liable to be thus introduced into the water. Animal organic matter is richer in nitrogen than most vegetable refuse, so that in practice the detection of much combined nitrogen, whether as organic matter, ammonium salts, or nitrates, is regarded as sufficient to indicate that the water has been contaminated with sewage or other animal matter. If much organic matter of animal origin be present there must always be considerable risk of disease producing organisms finding their way into the bodies of those who drink it; and though such contaminated water may be, and often is, drunk for years with impunity, its consumption is decidedly dangerous.

Another substance characteristic of sewage is common salt; consequently the presence of much chlorine in a water is generally indicative of sewage contamination, unless the water is derived from some rock which contains salt, or is collected near the sea.

What has been said has an important bearing upon the location of the farm wells. Dangers of seepage from the out door privy and the barn-yard must be avoided by locating the well at a proper distance from both and on higher ground. Even these precautions may not always entirely remove the danger of contamination.

Analyses, quoted from Ingle, of typically good and bad drinking waters, are given below.

Composition of Good and Bad Drinking Waters.

Constituents	Good water Parts per million	Bad water Parts per million
Total solids.....	63	530
Nitrogen as nitrites and nitrates....	0.25	7.8
Free ammonia.....	0.03	4.3
Albuminoid ammonia.....	0.07	0.9
Chlorine	11.4	69
Tem. hardness.....	1.4	102.9
Per. hardness.....	34.3	205.9
Total hardness.....	35.7	308.8

By hardness is meant the parts of calcium carbonate equivalent to the total amount of calcium and magnesium salts present in one million parts of the water.

By albuminoid ammonia in the above table is meant the quantity of ammonia, which is evolved from the water by the decomposition of organic nitrogenous substances when distilled with an alkaline solution of potassium permanganate.

Surface water. Rivers, ponds and lakes belong to this class. Most rivers originate in springs, so at first their water resembles that of their source. A considerable influx of surface water, however, generally enters the river and alters its composition. The composition of the waters of ponds or lakes will be much like that of the creeks and rivers flowing into them. The surface water usually contains less dissolved matter than spring water, but often more organic matter and suspended particles. The composition of the river water depends greatly upon the character of the rocks from which it is collected. When the surface consists of igneous rocks or of sandstone, the water is usually soft, while in lime stone districts it will be hard. Some rivers, as for example the Trent of England, are rich in calcium sulphate and to this fact the excellence of the Burton ales has been

ascribed. The remarkable softness of the river Dee, which flows through the granite district of Aberdeenshire, England, has also received special notice.

The following table represents the average composition of several well known lake waters of Wisconsin.

Composition of Wisconsin Lake Waters.

	<i>Parts per Million</i>		
	Lake Mendota	North Lake	Devil's Lake
Silica	1.1	3.0	2.2
Alumina and Iron....	0.8	0.6	0.6
Lime	40.1	66.2	4.5
Magnesia	42.3	46.4	1.8
Sulphur trioxide.....	10.3	11.1	6.7
Chlorine.....	2.0	4.0	8.2

The softness of the water of Devil's lake is also to be attributed to the fact that it is located in a sandstone country.

River water rarely contains large quantities of calcium carbonate such as occur in some springs, since, owing to the free contact with air it never retains very large quantities of dissolved carbon dioxide. Calcium sulphate in river water is usually accompanied by sodium chloride and magnesium salts.

In thickly populated and manufacturing centers the rivers are contaminated with the sewage and trade effluent of the towns and villages, and thus often become foul and bad-smelling. This is to be deplored both on account of the annoyance and injury to health which they cause, and also because of the serious loss to the community of the valuable combined nitrogen and other manurial constituents contained in the sewage. It is estimated that the Mississippi river carries daily to the sea 50 to 100 tons of nitrogen as nitrates. In some cities of America, as well as in Europe, the sewage is pumped directly to nearby lands called "sewage farms," where it is allowed to run at intervals between

thrown-up earth ridges. On these ridges various crops, especially vegetables, are grown, with the resultant utilization of the manurial constituents of the sewage.

The amount of suspended matter in river water varies enormously, depending upon the rain fall, the character of the surrounding soil, and other circumstances. Soft waters or those containing carbonate of soda, are often muddy, while hard waters tend to deposit their suspended clay and become clear. In some cases the quantity of suspended matter is very great, and a dense muddy river, if it over-flows its banks, deposits upon the soil a layer of finely divided particles of materials brought down from higher up the valley. The sediment is often rich in plant food and forms an important fertilizer. In some places in England, land is systematically treated with the flood water in order to increase the thickness of the soil. The process is known as "warping" and the "warp" soils are extremely rich and fertile. The Nile river in Egypt affords, on a large scale, a still better example of a river used in this manner.

In countries of limited or unevenly distributed rainfall, as in many of our western states, irrigation is often practiced. In this case, since there is very little drainage, the composition of the water used is of importance. If the water is charged with common salt, sodium sulphate or sodium carbonate, there is grave danger of the surface-soil, through the prolonged evaporation and concentration of the water, becoming charged with the soluble matter to such an extent as to seriously interfere with plant growth. The soil is then said to become "alkali." This condition may also arise from accumulation-in-place of the salts, produced by the weathering of the rocks. The slight rain fall is insufficient to produce percolation through the soil and carry the accumulating salts into the under ground water system. This produces a sterile condition which may be caused by sodium sulphate and chloride (white alkali), or by sodium carbonate (black alkali).

Different crops are possessed of different resisting powers to these salts. As a rule sodium carbonate is the most effective in causing injury to plants and sodium sulphate the least. Fortunately, however, "black alkali"—i. e., sodium carbonate—can be rendered almost harmless by the application of gypsum to the soil, which decomposes the sodium carbonate with formation of the very much less harmful substances, sodium sulphate and calcium carbonate. If "white alkali" is due to common salt, it cannot be cured except by drainage.

According to results accumulated in this country, and tabulated by Ingle, the following figures give the highest proportion of sodium chloride, sodium sulphate and sodium carbonate which may be present in soils without injury to the plants named. The figures represent the amounts in pounds of the various constituents present in the upper four feet of soil per acre:

Plant	Sodium Chloride	Sodium Sulphate	Sodium Carbonate
Grape.....	800	40,800	7,550
Fig.....	9,640	24,480	1,120
Orange.....	3,360	18,000	3,840
Apple.....	1,240	14,240	640
Peach.....	1,000	9,600	680
Oriental sycamore.....	20,320	19,240	3,200
Salt bush.....	12,520	125,640	18,560
Alfalfa, old.....	5,760	102,480	2,360
Sugar beet.....	5,440	52,640	4,000
Radish.....	2,240	51,880	8,720
Wheat.....	1,160	15,120	1,480
Barley.....	5,100	12,020	12,170
Sorghum.....	9,680	61,840	9,840

In this table it is assumed that the weight of soil to a depth of four feet per acre is 16,000,000 pounds, or that each acre-foot of soil weighs 4,000,000 pounds. One per cent of any constituent would then correspond to 40,000 pounds per acre to a depth of one foot, one-tenth per cent to 4,000 pounds, and so on.

Sea water varies in composition, dependent upon the locality at which it is taken. Its composition is affected by the influx of fresh water from large rivers, etc., but far out from land it is very constant in composition. The average amount of total solid matter is about 34,000 parts per million. Thorpe, in 1870, found in the water of the Irish sea the following constituents expressed in parts per million:

Sodium chloride.....	26,439	Magnesium nitrate.....	2
Potassium chloride.....	746	Calcium sulphate.....	1,332
Magnesium chloride.....	3,150	Calcium carbonate.....	48
Magnesium bromide.....	71	Ammonium chloride.....	0.4
Magnesium sulphate.....	2,066	Ferrous carbonate.....	5
Magnesium carbonate.....	Trace	Silicic acid.....	Trace

In certain lakes having no connection with the ocean, the concentration of the water becomes much greater, and the total solid matter may reach even seven or eight times that found in the ocean. Examples of such water are found in the Dead Sea and the Great Salt Lake of Utah.

CHAPTER V

THE PLANT

The growth of plants is the result of a series of chemical changes which first assume prominence in the sprouting seed, with the ultimate object of producing seed for a succeeding generation. The effects of these changes become inconspicuous in resting seeds, but their activity ceases only with the death of the organism.

Germination. A seed is essentially an embryonic plant surrounded and protected by a supply of reserve materials which serve as food until the young plant can forage for itself. These reserve compounds are more or less complex structures involving simple plant-food constituents derived from the air and soil. The changes by which they are altered for the use of the seedling are produced by sensitive compounds known as *enzymes*.

These compounds are not endowed with life, but they are probably closely related in composition to the complex, nitrogenous compounds known as proteins, which form the basis of living matter, and with whose chemical changes the life processes of plants and animals appear to be very closely connected. The exact nature of enzyme action is not known. One of the older and more prominent theories of this action was based upon the sensitiveness of these bodies and their proneness to undergo decomposition. It attributed their effects to a sympathetic relation whereby they induced instability, or accentuated conditions already unstable, in certain other compounds and caused them to break down. This theory is insufficient for we now know that enzymes can effect the construction, as well as the destruction, of some compounds. Under proper conditions of temperature and moisture small amounts of a given enzyme induce changes in a large amount of matter, each kind of enzyme acting upon a specific compound or group of compounds. Thus, a specific type

of enzymes, designated as proteolytic in nature, alters the protein compounds of the germinating seed; an enzyme known as diastase converts starch to dextrines and sugar; a lipase or fat splitting enzyme alters fats only, while still another type of enzyme liberates phosphorus, calcium and other ash constituents from organic compounds of the seed. Phytase, which occurs in wheat and other grains, is an example of the last mentioned class of enzymes. It breaks up the compound known as phytin, producing simple soluble compounds of calcium, magnesium, potassium and phosphorus.

Consideration of this specific relation between enzymes and organic compounds and extension of our knowledge concerning the chemical structure of the substances involved therein have led to a theory which likens the action of an enzyme to that of a key upon a lock, in the sense that each key fits and trips only the particular lock to which it is adapted. This is more complete than the older theory, for it ascribes to the enzyme power to reconstruct its specific compound just as the key can lock as well as unlock. It is in harmony with the known reversibility of some enzyme actions.

The fragments of compounds resulting from enzymatic action in the seed, combine with the oxygen of the air, always required for germination, and either yield energy for the growth of the young plant, or pass as soluble compounds with the sap into the growing seedling, there to be reconstructed into compounds forming the tissues of the young plant.

By the time the reserve compounds of the seed are exhausted the young plant is differentiated into separate organs, known as *root*, *stem* and *leaf*, by means of which it can assimilate raw food materials from the air and soil.

Functions of the root. The root is an organ of great importance in the assimilation of food. Large amounts of water required by the growing plant, are taken from the soil by means of the root and it is through this means that the plant obtains its nitrogen and ash constituents.

The activity of this organ in this connection is shown by the following figures quoted from King. The table expresses the pounds of water required to produce 1 pound of dry substance in the plant.

Pounds of Water Required to Produce One Pound of Dry Substance.

Kind of Plant	Pounds of Water
Dent Corn.....	309.8
Barley	392.9
Oats	522.4
Red Clover.....	452.8
Field Peas.....	477.4
Potatoes.....	422.7

When we consider that field crops require an amount of water from three hundred to five hundred times as great as their own dry weight, and that all of their nitrogen (except in the case of leguminous plants) and all of their ash constituents are derived from the soil with this supply of water, the great importance of



Showing the power of the rutabaga to obtain its phosphorus from insoluble phosphates.

- Box. 1. Soluble phosphoric acid.
- Box 2. Insoluble phosphoric acid—Florida rock.
- Box 3. Insoluble phosphates of iron and aluminum.
- Box 4. No phosphate added.

the function of assimilation performed by the roots becomes evident.

While some plants, as for example, tobacco and the potato, require liberal supplies of plant food in readily available form, others, especially the cruciferae (turnip, rutabaga and related plants) and some of the gramineae (cereal grains and grasses), display marked ability to attack resistant compounds in the soil and obtain food from them. This difference is well illustrated by the following data obtained by Merrill at the Maine Experiment Station in studying the availability of phosphorus, when supplied in various forms to different crops. Other requirements of the plants than that for phosphorus were amply supplied. The figures express the percentage yield of dry matter, the yield with no phosphorus being taken as 100 per cent:

Plant Family	Crop	No Phos- phorus	Phos- phorus in ground Florida rock	Phos- phorus in iron and aluminum phosphate	Phos- phorus in water soluble forms
		Per cent	Per cent	Per cent	Per cent
Leguminosae.....	Peas	100	140.4	108.6	191.8
	Clover	100	205.1	152.4	262.2
Graminae.....	Barley	100	117.7	128.1	232.5
	Corn	100	273.6	316.6	704.2
Solonaceae.....	Potato	100	114.1	121.6	161.2
	Tomato	100	255.7	218.8	376.1
Cruciferae.....	Turnip.....	100	159.0	204.2	226.6
	Rutabaga...	100	286.0	216.6	378.1

These data show a widely variant power on the part of plants to assimilate comparatively insoluble and unavailable compounds of phosphorus. The great superiority of corn over barley and of the tomato over the potato in utilizing the insoluble phosphates is interesting as a demonstration that assimilating power is not uniform for members of a plant family, but is a characteristic of the individual species. The cruciferae, however, as a family,

are notably efficient as phosphorus gatherers, while the grass family is characterized by high assimilation of silicon.

The well known power of roots to etch the surface of limestone is due to excretion of carbon dioxide from this organ of the plant, and differences in ability to assimilate food materials may be explained partly by differences in carbon dioxide output.

If the stem of an actively growing plant be severed at its junction with the root and replaced by a pressure gauge, it will be found that the root exerts an upward pressure amounting in some cases to more than 30 pounds per square inch. According to Wieler this pressure has been found sufficient to support a column of water of the following heights in the plants indicated :

<i>Plant</i>	<i>Height of water column supported by root pressure</i>
White Mulberry	6.5 inches
European Ash.....	11.4 "
Castor Oil Plant.....	181.3 "
Stinging Nettle.....	249.7 "
Wine Grape	581.6 "
White Birch.....	755.0 "
Sweet Birch (Black Birch).....	1043.2 "

By this so-called "root pressure" the root is believed to function in the movement of water through the plant.

In biennial root crops such as the beet, the root of the first year's growth serves as a magazine for food from which the second year's growth is re-inforced for the production of seed. This reinforcing material is usually starch or sugar, with small amounts of nitrogen compounds and ash constituents.

The stem. The active portion of the stems of plants consists essentially of a system of tubes formed by continuously connected cells. These tubes serve as channels for the transportation of water and food materials and are surrounded by protecting and supporting tissue. In the stems of endogenous plants, as in the corn and the bamboo, the tough, smooth bark is formed by aggregates of the dead remains of conducting cells and newer growths are added by increments of these cells in the soft pith

toward the center of the stem. Groups of these cells, which traverse the pith of the stalk longitudinally, are familiarly known as the fiber of hemp and the threads of the corn stalk. The stems of exogenous plants like the oak and maple, which produce new tissue outward from a compact, central heart-wood, consist of a tough, supportive core of the older and denser tissue surrounded by the growing cambium layer. This whole structure is surrounded and protected by a layer of dead cells forming the outer bark. Sap is conveyed about these plants through channels in the cambium layer or inner bark, and may be obtained in quantity from some trees, as from the sugar-maple, by tapping into the inner bark and contiguous woody tissue in early spring, when the rapidly developing buds are drawing upon reserve food supplies in the trunk. In the case of the maple tree, starch and other reserve carbohydrates are in process of transportation to the buds in the form of sugars which may be recovered as such by concentrating the sap.

The stems of some plants have the appearance of roots from the fact that they exist below the surface of the soil. The pods of the peanut, for example, ripen in the ground because the flower stems lengthen and penetrate the soil as soon as the blossom falls.

Root stocks or rhizomes are subterranean stems, each joint or node of which puts out both leaf buds and roots. Each node is thus equipped to become an independent plant as soon as it is isolated from the parent stem. It is to this fact that the extreme troublesomeness of quack grass is due. Cultivation, except in a favorable season of prolonged drought, serves to increase the pest. Asparagus is another example of a plant growing from a rhizome and well illustrates the function of the stem as a food magazine.

Tubers are fleshy enlargements of the tips of subterranean stems. Their "eyes" mark the position of buds, which distinguish them from true roots. Each of these eyes is the precursor of one or more new plants. The tubers of the potato, arrow root, and some other plants, are of great value as food because

of their high starch content. In these cases the stems serve as storage places for reserves of plant food. The bulbs of the onion, lily and other plants, are permanent buds, formed of fleshy, closely packed scales. They are properly a part of the stem of the plant, serving as reserve material for growth. The fleshy portion of the crocus, gladiolus and some other plants is not a bulb, but is an enlargement of the base of the stem.

The stem also serves as a means of support for the leaves and fruit, favoring the exposure of both to the air and sunlight, essential to the chemical processes which promote growth.

The leaf. The leaf is the seat of greatest constructive activity in the plant. The important process of transpiration, or escape of water from the plant, is controlled by minute openings upon the plant's surface. These openings, known as stomata, occur in small numbers upon the stems of plants, but they are most abundant upon the leaves. They are especially numerous upon the protected under surface of leaves, where, as in the case of the cabbage or apple, their number may reach 200,000 per square inch. The outlet of a stoma is lined by two peculiar cells which face each other, forming a miniature mouth opening outward from the surface of the leaf. These cells, called guard cells, are the seat of control in the action of the stomata. When the water supply is abundant and the plant cells are turgid, the guard cells are elongated vertically to the leaf surface and contracted parallel to it, thus drawing apart and exposing an outlet for the evaporation of water. On the other hand, when the water supply is limited and the plant cells wilt or shrink, the guard cells flatten and become elongated parallel to the leaf surface, thus automatically closing the stomata and checking evaporation from the plant. This process partly controls the supplying of plant food from the soil and is an important means of maintaining optimum temperatures in the plant as a result of increased or decreased evaporation of water.

The leaf inhales air through the stomata. From this supply of air it assimilates carbon dioxide for the construction of plant

compounds and employs oxygen in the process of respiration analogous to that of animals.

The magnitude of the former process can be realized when we recall that a 12 ton crop of corn requires for its production four tons of carbon dioxide. To secure this amount, the plants must respire 10,000 tons of air or approximately one-fourth of the total amount over an acre of land.

The construction of organic compounds, which is a characteristic function of the plant occurs principally in the leaf. It is initiated by the green coloring matter known as chlorophyll. This substance has been shown to be a specific but complex chemical compound. It may be seen under the microscope as granules clustered within the cells of all green plant tissues. In some colorless fungi and lower plants it is lacking. Such plants do not construct organic compounds independently but derive them from previously existing vegetation. The green color of plants is due to chlorophyll, as may be shown by extracting it with alcohol. Such an extract is intense green in color, due to the chlorophyll removed by the alcohol, while the extracted tissue is bleached and colorless. In some unexplained manner this sensitive compound, under the influence of light, induces the union of carbon dioxide assimilated from the air, and water conveyed from the root, with the production of the first carbohydrates of the plant.

It is not known whether this first product is starch, sugar, or a simple precursor of these compounds. The process involves the elimination of two parts of oxygen for each part of carbon dioxide assimilated, as shown by the following general expression:—Carbon dioxide + Water = Carbohydrate (Dextrose) + Oxygen.

The evolution of oxygen in this process has been proved by experiments in which living leaves were confined in inverted jars of water. A gas which collected above the water responded to tests for oxygen and its volume was found to be equivalent to the carbon dioxide taken up. The plant also performs through the

leaves the process of respiration or breathing, in which oxygen of the inspired air combines with compounds of the plant, with an accompanying elimination of carbon dioxide. This process is most evident in darkness since it is not masked then by the more extensive process of carbon dioxide assimilation. By combining the carbohydrates as a basal material with nitrogen and sulphur brought from the soil, the leaf cells produce a further class of organic compounds known as proteins. Nitrogen and sulphur usually enter the plant as highly oxidized compounds and are built into the proteins after suffering reduction or loss of oxygen.

The leaf functions also as a temporary reservoir for migratory compounds which, at the death of this organ, return into the general circulation of food materials in the plant. This is true particularly of trees and other perennial plants, whose dead leaves are skeletons consisting chiefly of cellulose compounds and unessential ash constituents like silica, the more important nutrient compounds and ash materials having returned to the stem of the plant.

Flowers, fruits, and seeds are pre-eminently seats of constructive processes in which chemical reactions are especially active and significant. Fragmentary protein structures, possibly the amino-acids, are here withdrawn from solution in the sap current and retained as finished proteins. Soluble carbohydrates are converted to starch or to some of the fats, which are present in the seeds. Ash constituents for the young plant of the next generation are stored away as constituents of organic compounds. Absorption of oxygen is especially marked in these organs and may be accompanied by considerable heat production. In the case of the Italian arum lily it has been observed that the large pistil absorbs in one hour nearly 30 times its volume of oxygen with a resultant temperature of over 100° Fahr.

The end of all this activity is the production of mature seed containing a finished plant embryo, a store of food materials, and enzymes to inaugurate the process of germination. At this stage

of growth, the leaves, stems and roots are contributing their reserves for the production of seed. Migration of food constituents, especially of starch, nitrogen compounds and ash constituents, from the root or leaves now assumes prominence. While the ash constituents accumulate in the seed only in small amounts, sufficient for the growth of a vigorous seedling, some of the organic reserve compounds may be stored in excess, giving distinctive character to the seed. This is true of starch, which gives the cereal grains peculiar value for the manufacture of foodstuffs and of alcoholic products. It is also true of fats and proteins, which give to cotton and flaxseed high commercial values as sources of oils and as protein-furnishing constituents of rations for live stock. Starch and fat serve the young seedling as sources of energy for growth and as material for carbohydrate construction until it becomes independent of the seed; the proteins of the seed furnish simple nitrogenous structures from which the proteins of the seedling are formed.

Compounds of the plant. As a result of the activity of the various plant organs, there is produced a great variety of compounds, partly transitory in nature and partly of permanent character. The following classification is a brief plan of division for the compounds of the plant:

Water			
		Non-Nitrogenous	- Carbohydrates - Fats and waxes - Terpenes and essential oils - Organic acids
	Organic or combustible matter		
		Nitrogenous	- Proteins - Amino-acids - Amides - Amines and alkaloids
Dry Matter			
	Ash containing compounds	- Salts of organic acids - Inorganic compounds	

Water holds a place in the chemistry of the plant the importance of which can hardly be realized. Besides its physical functions of transporting food materials and regulating the temperature of the plant, it is responsible for maintaining the turgidity of the individual cells, thus giving form and rigidity to immature

and succulent growth. The entrance of many comparatively insoluble compounds into the plant is made possible when they assume a hydrated form, that is, when they are combined with water. Silicon, for example, which forms comparatively insoluble soil compounds, is supposed to enter the plant as silicic acid, which through dehydration or loss of water becomes deposited as silica. Water is the chief constituent in green plants, its amount varying from 80 per cent in grasses to 90 per cent in root crops. Its amount decreases at the maturing stage. For example, timothy grass, which contains on the average 80 per cent of water, has when dead ripe 63 per cent of this constituent.

The importance of water in the transformation of carbohydrates will be shown in following paragraphs. It is important to observe here that the constituents of water form 55.5 per cent of starch and that their proportion is equally prominent in other carbohydrates. Water bears similar importance in the structure and transformations of all the other plant compounds.

The carbohydrates form a widely distributed and prominent group of compounds in the plant kingdom. They may be classed in order of increasing complexity as follows:

Mono-saccharides.

Di-saccharides.

Tri-saccharides.

Poly-saccharides.

Mono-saccharides are commonly represented by dextrose or glucose, which occurs in most fruits. Artificial dextrose or "glucose syrup" is prepared commercially by the action of hot, dilute sulphuric acid upon starch and subsequent removal of the acid by means of lime. This is a hexose or six-carbon sugar, being composed of six parts of carbon combined with the equivalent of six parts of water. This structure, to which the name carbohydrate (signifying carbon-water union) owes its origin, may be confirmed by gently heating the sugar in a glass tube. Water separates from the compound and collects on the adjacent cold

surface of the tube, while the remaining blackened or charred portion denotes the presence of carbon. Glucose is a product of the decomposition of all higher carbohydrates. It is about two-thirds as sweet as common sugar.

very **Levulose** or fructose is a mono-saccharide of the same general composition as dextrose and has many properties in common with it. The two sugars are commonly associated in fruits. Levulose is abundant in honey where it exceeds the amount of dextrose. the two forming about 75 per cent of the product.

No other hexose-sugars occur free in plants, but galactose is a compound of this class. It is formed by hydrolysis or addition of water to a group of poly-saccharides, called galactans, which occur in plants.

Di-saccharides are represented in the plant kingdom by two sugars. Sucrose, or cane and beet sugar, occurs in many plants. notably in the juice of sugar cane (16 to 18 per cent), in the sugar beet (10 to 18 per cent), and in the sap of the sugar maple (about 90 per cent of the solids). The sweetness of the sap of corn and sorghum stalks and of peas and other seeds is due to appreciable amounts of sucrose. This sugar differs from the mono-saccharides in that it crystallizes readily, and this property is taken advantage of in purifying the commercial product. By the action of the enzyme invertin, which occurs in yeast, sucrose is converted into equal parts of dextrose and levulose, hence the designation "di-saccharide."

This process of "inversion" may be accomplished also by boiling sucrose with dilute acids, the product by both methods being known as "invert sugar." The change involves the addition of one part of water to each part of cane sugar and this reaction characterizes the inter-relations of carbohydrates in general, which are largely dependent upon differences in content of the water-forming elements.

Maltose or malt sugar, is a di-saccharide occurring in small amounts in seeds. Its amount is considerably increased as a result of germination, in which the enzyme known as diastase converts starch to dextrines and maltose. Crystallized maltose

contains one part of water. This makes possible a direct conversion to lower sugars, and upon inversion by enzymes or acids, one part of this sugar yields two parts of dextrose.

Tri-saccharides are represented in plants by raffinose. This sugar occurs in cotton seed and the germs of wheat, barley and other seeds. It sometimes occurs in sugar beets, especially as a result of disease or injury, and in quantity sufficient to interfere with the refining of the beet sugar. Raffinose inverts to equal parts of dextrose, levulose and galactose.

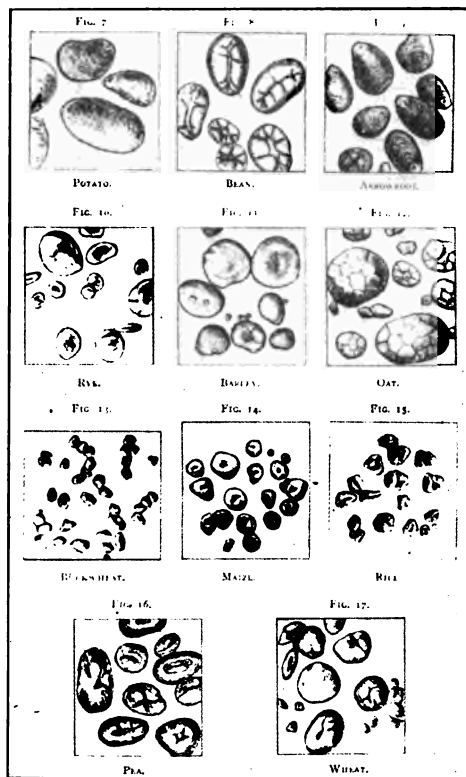
Poly-saccharides are the most abundant of the carbohydrates. *Starch*, which is one of the simpler members of this group of compounds, is an unknown multiple of a chemical group containing six parts of carbon and the equivalent of five parts of water. It may be considered as a multiple of the compound dextrose, in which each part of dextrose has lost one part of water. Diastase of sprouting seeds and the enzyme ptyalin, which occurs in saliva, convert starch to a mixture of simpler, gummy carbohydrates, known as dextrines and then to maltose.

Hot, dilute acids invert starch completely to dextrose and by this means, in addition to the action of diastase, the chemist determines the amount of starch in plants. This process is also, as has been stated, the basis for the commercial production of corn syrup or glucose syrup. The large amounts of starch in cereal grains, as barley and corn, and in some root crops, as the potato, give them value for the production of alcohol and alcoholic liquors. Alcohol is not formed directly from starch, but is a product of the fermentation of the sugars to which starch may be converted by malt extract.

The amounts of starch found in some plants and plant products are as follows, expressed in per cent of the air dried material:

	Per cent		Per cent
Wheat flour.....	66.55	Rice grain.....	79.4
Corn meal	71.00	Barley grain.....	62.0
Corn plant (ears glazed)....	15.40	Potato tuber.....	75.5
Corn stover.....	0.96	Bean grain.....	42.7
Oat meal.....	56.23	Pea grain.....	40.5

Some of the grains and roots named above are familiar as sources of commercial starch. This is true of corn and the potato. Tapioca is a starch preparation from the root of the cassava plant and sago starch is taken from the interior of the trunk of the



Starch granules from various sources.

sago palm. A single tree of the latter variety may yield 500 pounds of sago.

Individual starch granules are readily detected in plant cells by means of the microscope and under these conditions, the characteristic markings of the granules of different plants become of value in identifying the source of the sample.

Dextrine of commerce is a mixture of compounds varying in complexity. Its gummy nature gives it value as an adhesive paste. Stick-labels and postage stamps are coated with dextrine. Mixtures of dextrines occur in the grains of cereal plants and their amount increases at germination as a result of the decomposition of starch. The relative proportions of chemical elements in starch and the dextrines are the same, but the latter are apparently simpler groups of a basal compound ($C_6 H_{10} O_5$), ascending in complexity toward the composition of starch. Dextrines are precursors of the simple carbohydrate maltose, which occurs in germinated grains.

Galactans are complex poly-saccharides occurring particularly in the seeds of leguminous plants, in some of which they are the chief carbohydrates. In the process of hydrolysis, these compounds combine with water to form the comparatively simple hexose known as "galactose."

Cellulose, the basal constituent of woody fibre, is a poly-saccharide of great importance for its tenacity and rigidity, which give form and resistance to the walls of mature plant cells. It rarely occurs free in the plant, but rather as a constituent of compound celluloses, such as the incrusting, lignified celluloses or ligno-celluloses of cell walls. Cotton and hemp fibres are single, elongated plant cells, whose walls are composed of nearly pure cellulose. By treating these fibres successively with hot, dilute acid, with hot, dilute alkali and finally with chlorine gas, and washing out the products formed, the purest known cellulose has been obtained. It is evident that to resist such treatment this compound must be extremely stable. It can be brought into solution, however, by certain reagents, and when treated with strong sulphuric acid, followed by diluting with water and boiling, it is broken down and partially converted to dextrose.

This brief discussion of the properties of the various carbohydrates in connection with their common products of decomposition, may serve to indicate a common basis of structure for this group of plant compounds. Thus, by the union of two mono-

saccharides, we have a di-saccharide. An addition of another simple sugar produces a tri-saccharide. Further increments result in dextrines of increasing complexity and decreasing solubility until we have as a product, starch. This is a substance insoluble in cold water and decomposes with some difficulty.

By some internal re-arrangement of the chemical elements involved in the carbohydrate molecule, we may have cellulose produced instead of starch. This is an extremely resistant and comparatively permanent compound in which apparently the stability of the carbohydrates has reached a maximum. These constructive processes take place only in the plant. We can follow them in the chemical laboratory only in a reversed order, proceeding from the complex to the simple. Our knowledge is therefore concerned with the general relations of these compounds, rather than with the actual changes by which they are successively produced in the plant.

The pectin substances and pentosans should be classed under the general head of carbohydrates.

Pectins are insoluble bodies which occur in the flesh of most unripe fruits. Upon boiling with water they yield various poorly defined compounds of gelatinous nature, sometimes referred to as pectoses or pectic acids. It is to these bodies that the "setting" of fruit jellies is due. On treatment with weak acids or alkalis, they yield simple sugars, thereby disclosing their carbohydrate nature. Besides dextrose, they yield a class of sugars containing five parts of carbon and hence designated as pentoses. The mucilaginous substances of flaxseed, quince fruit and parts of many other plants, are of pectin nature.

Pentosans are present in considerable amounts in certain gummy exudations of plants, such as cherry gum, which oozes from wounds on trees of the *prunus* genus, and gum arabic of tropical *Acacias*, a genus of leguminous plants. The pentosans of gum arabic yield on hydrolysis a pentose sugar called arabinose. Xylose is a pentose sugar obtained from the so-called wood gums, or pentosans which are abundant in straws and some

grains. The pentosans are intimately associated with the cellulose of plant tissue. They differ from their corresponding sugars, the pentoses, by the equivalent of one part less of water. Upon boiling with dilute mineral acids each of these compounds takes on one part of water. Araban yields arabinose readily, while xylan yields xylose only gradually under these conditions. This behaviour demonstrates the carbohydrate nature of the bodies under consideration. The following percentages of pentosans have been found in some plant materials:—

Hays.....	20 per cent
Gluten feed.....	17 “
Linseed meal.....	13 “
Brewers' grains	24 “
Wheat Bran	24 “

From 60 to 90 per cent of these compounds in feeding stuffs disappears from the digestive tract of herbivora. This may be partly due to bacterial fermentation. Since pentosans, when assimilated by the animal, appear to have a value similar to that of starch, it is evident that in some cases they may be of considerable importance as constituents of the carbohydrate material of feeding stuffs. *here*

Fats are uniform in their general composition, consisting of one part of glycerine combined with three parts of fatty acid. The latter constituent controls the nomenclature of the fats. Thus, for example, the fat containing three parts of stearic acid is known as “tri-stearin,” or more commonly as “stearin.” Fats which contain two or three different fatty acids in combination with the same part of glycerine are called “mixed glycerides.” Acetic acid, which causes the sour taste in vinegar, is a typical example of the fatty acids, the simpler members of this group of compounds being volatile liquids of characteristic, pungent odor similar to that of the acid cited. The higher members of the acetic acid series are solid substances; and the fats in which they occur are also solid, in distinction from liquid fats or oils

produced by lower fatty acids. These acids rarely occur free, as in the case of formic acid, which produces the sting of the nettle plant; but they usually occur as constituents of neutral fats. Oleic, linoleic and linolenic acids are types of three other series of fatty acids which are more abundant in plants than the acetic acid series. In distinction from the latter, these acids are characterized by loose chemical bonds, by virtue of which their fats take on oxygen, iodine and other active chemical elements. Thus, on prolonged exposure to air, olein takes up one part of oxygen, linolein takes up two parts and linolenin takes up three parts, by weight. This change is accompanied in proportion to its extent by "setting" or hardening of the oils concerned. As a result, while olein remains liquid even when exposed to the air in thin layers and is characterized as a "non-drying" oil, increasing proportions of linolein and linolenin produce consecutively the "semi-drying" and "drying" oils.

The high percentages of the latter oils in linseed oil enhance its value as a vehicle for paints, because, having distributed the pigments which it carries, it gradually "sets" and forms a durable protective coating. If the process of oxidation in such an oil is hastened by exposing it in thin layers upon inflammable material, sufficient heat may be generated to cause spontaneous combustion. Ignorance of this fact has caused destructive fires. due to oil soaked rags and similar material.

Plant fats consist for the most part of mixtures of olein and linolein with smaller amounts of stearin, palmitin and lower members of the acetic acid series. The proportions of fats are such as to maintain a liquid state at ordinary temperatures and produce the oils of the seed of cotton, castor bean, flax and other plants. The simple fats differ from carbohydrates by a higher content of carbon and hydrogen and lower oxygen content than the latter. This higher content of combustible elements renders fats of greater fuel value than the other leading plant compounds, because of greater oxygen consumption during combustion. This

property assumes great importance, as a source of heat or energy, when the fats are oxidized in the sprouting seed or in the animal body.

In some remarkable manner, the plant reverses this process and constructs its fats from carbohydrates with elimination of oxygen. The following figures show the relative composition of a typical carbohydrate and a typical fat.

	Per cent Carbon	Per cent Hydrogen	Per cent Oxygen
Carbohydrate (starch).....	39.98	6.71	53.31
Fat (stearin).....	76.78	12.45	10.77

Fats occur in plants chiefly as reserves in the seed. The seeds of cereal plants such as corn and oats contain only small amounts of fat. Flaxseed, cotton-seed, the castor bean and other seeds contain oil in sufficient amount to render its extraction on a commercial scale both feasible and profitable. The fat content of some common seeds is as follows:—

	Per cent		Per cent
Barley	1.8	Cotton	20.0
Wheat	2.0	Sunflower	21.0
Corn	5.0	Flax	33.5
Oats	5.0	Castor bean.....	50.0

The old fashioned home process of soap-making by boiling waste grease with leachings from wood ashes depends upon the fact that alkali metals, in this case the potassium or "potash" of wood ashes, will displace glycerine from fats. Super-heated steam also breaks up fats into glycerine and fatty acids, and in common with the alkali treatment mentioned above, the process is called saponification. The glycerine of commerce is a by-product from this process in the soap industry. Since mineral oils cannot be saponified, we have here a means of distinguishing them from fats.

Lecithin is a compound closely related to the fats. In place of one part of fatty acid in a normal fat it contains phosphoric acid combined with a nitrogen-containing, basic compound known

as choline. Lecithin is sometimes referred to as a "phosphorized fat." It occurs in the seeds of cereals and to a greater extent in the seeds of legumes.

Waxes have some properties in common with the fats and are frequently associated with them in the plant and separated with them by methods of extraction. They differ from fats in that they contain an alcohol of higher weight in place of glycerine, this alcohol being combined with the fatty acid in equal parts. Chinese wax and the carnauba wax obtained from the leaves of a South American palm are single compounds, while the waxes found in the seeds of the palm, flax, cotton and other plants are mixtures. The "bloom" of leaves and fruits, which serves as a protective coating, is composed of waxes. These compounds can be converted to soaps in the same manner as fats, but they yield, of course, other alcohols in place of glycerine.

Terpenes, essential oils, camphors and resins form another group of closely related plant compounds. The terpenes belong to a class of chemical compounds known as hydro-carbons, which are composed of the elements carbon and hydrogen only. They are partly liquids, such as spirits of turpentine, and partly solids, such as rubber and gutta-percha. As in the case of carbohydrates, a classification of these bodies in order of complexity is in use which separates them into mono-, di- and poly-terpenes. Terpenes are products of pitch yielding trees. Turpentine is a terpene of special value in the paint industry as a "thinner" or solvent for fats and oils.

The essential oils to which the characteristic odors of flowers and flavors of fruits are due are partly hydro-carbons, as in the case of oil of turpentine and oil of lavender. Others, such as oil of wintergreen and almond oil, contain some oxygen. Heliotropin of the heliotrope and the compounds to which the aroma of the banana, orange and other fruits is due, are essential oils. The pleasing smell of new mown hay is due to the essential oil, coumarin. These compounds are of value in the compounding of perfumes, cordials and medicines. They are of special significance in foods because of their probable effect on palatability.

Camphors are obtained by the distillation of certain tropical woods. They differ from terpenes in containing oxygen added to the elements of the latter. The two classes of compounds are apparently closely related products of the chemical processes of the plant.

Resins occur in pitches and are closely allied in composition to the camphors. Like terpenes and camphors they may be distinguished from fats by failure to produce soaps by the usual process of saponification.

Organic acids often occur in plants in considerable amounts and are responsible for the sour taste frequently observed. They are produced by the fermentation of carbohydrates and rarely occur free but usually as acid or neutral salts of potassium or calcium. The sourness of lemons is due to citric acid. The acid-potassium salt of oxalic acid occurs in sorrel and acid-calcium oxalate has been found in rhubarb. Malic acid is common in fruits, and exists as the acid-potassium salt in rhubarb and the acid-calcium salt in the berries of the mountain ash, tobacco leaves and other plants. The acid-potassium salt of tartaric acid is characteristic of the grape, and potassium and calcium salts of this acid are found in the pine-apple, sumac berry and other fruits. It is interesting to note in this connection that lactic acid develops in corn silage as a product of hydrolysis of dextrose and other carbohydrates. These acid compounds play an important part in the production of characteristic flavors.

The proteins are compounds of the greatest importance in the plant. They are of complex structure, containing not only carbon, hydrogen and oxygen, but also nitrogen and sulphur. This large number of constituents makes possible a variety and complexity of structure fitting them for the delicate and complicated reactions which characterize life processes. Proteins form the basis of the life-bearing protoplasm and nucleus of each plant cell. Although contained in every cell, they are localized chiefly in the seed and furnish nitrogen for the first protein structures of the seedling. Individual proteins are characterized by a con-

tent in fixed proportion of the simpler nitrogenous bodies known as amino-acids. Asparagin, which is a derivative of an amino-acid, occurs in freshly sprouted asparagus, peas and beans. It is produced from seed proteins by enzyme action and is, in part, eventually fitted into the proteins of the seedling.

Plant proteins may be classified briefly as follows:

1. *Albumins*: Soluble in pure cold water; coagulated by boiling; occur in seeds only in small amounts.

2. *Globulins*: Insoluble in water; soluble in salt solutions; separate out on diluting or saturating the solution. Most common and abundant of plant proteins. Occur in largest amount in the seeds of leguminous plants. Certain globulins appear to be characteristic of the seed in which they are found, as with avenalin of the oat, maysine of corn, and hordein of barley. Edestin, the globulin of the hemp seed, however, occurs in several grains.

3. *Alcohol-soluble proteins*: (Prolamins). Nearly or wholly insoluble in water; soluble in alcohol of from 70 to 90 per cent strength. They have been found only in the seeds of cereal plants.

4. *Glutelins*: Not dissolved by water, salt solutions, or alcohol; may be extracted by treating the residue of seeds from which the other proteins have been removed, with dilute alkaline solutions. Isolated and purified with much difficulty. The only well defined glutelins are glutenin of the seed of wheat and oryzenin of the seed of the rice.

5. *Conjugated (compound) proteins*: These proteins have been modified by combining with other compounds. They include nucleo-proteins, in which a large proportion of protein is combined with a small amount of nucleic acid. Phosphorus is present in these compounds, being contributed by the nucleic acid. Conjugated proteins of other types occur in the animal kingdom, but the exact nature of other preparations than nucleo-proteins from plants, assigned to this group of compounds, has not been clearly established. Such knowledge as we possess in-

dicates that only small quantities of nucleo-proteins occur in the entire seed and that they are chiefly in the tissues of the embryo, in which the nuclei of cells are most abundant.

The approximate amounts of some plant proteins found in seeds are given by Osborne as follows:

Protein	Source	Per cent in the dry material
<i>Albumins</i>		
Leucosin	Wheat grain	0.3 -0.4
Leucosin	Rye grain	0.43
Leucosin	Barley grain	0.3
Phaseolin	Kidney bean grain	2.0
Legumelin	Pea meal (free from outer seed coats)	2.0
Legumelin	Lentil meal (free from outer seed coats)	1.25
Legumelin	Horse bean meal (free from outer seed coats)	1.5
Legumelin	Vetch grain	1.5
<i>Globulins</i>		
Maysin	Corn grain	0.25
Phaseolin	Kidney bean grain	20.00
Avenalin	Oat grain	1.5
Conglutin	Yellow lupine grain	26.2
Legumin	Vetch grain	10.0
Legumin and Vicilin	Pea meal (free from outer coatins)	10.0
Legumin and Vicilin	Lentil meal (free from outer coatings)	13.0
Legumin and Vicilin	Horse bean meal (free from outer coatings)	17.0
Edestin	Corn grain	0.14
Edestin	Wheat grain	0.6 -0.7
Edestin	Cotton seed meal (oil free)	15.83
Edestin	Flax seed (grain)	17.6
<i>Alcohol soluble proteins</i>		
Gliadin	Rye grain	4.00
Gliadin	Wheat grain	4.25
Hordein	Barley grain	4.00
Zein	Corn grain	5.00
<i>Glutelins</i>		
Glutenin	Wheat grain	4.0 -4.5
Glutenin	Corn grain	3.5 (assumed)
Glutenin	Oat grain	11.25 "
Glutenin	Barley grain	4.50 "

Amino-acids, which have been referred to as constituents of proteins, occur free to a limited extent in plants. Their structure is that of fatty acids into which amino (NH_2) groups have been substituted for hydrogen atoms other than those of acid radicles. They are compounds of only weakly acid or even of basic properties. Amino-valerianic acid is a body of this sort which has been separated from white and yellow lupine plants of two to three weeks' age. Leucin, which is a substituted amino-acetic-acid, occurs in smaller amounts with the amino-valerianic acid. In some coniferous seeds the amount of arginin, another amino acid, exceeds that of the amino acids already mentioned. Arginin is a di-amino acid, that is, it contains two such amino groups.

Amides are nitrogenous compounds of another class which have been the object of considerable study in their relation to the feeding of animals. The proportion of the total nitrogen in this form at the time of harvesting the plant is of considerable importance because of the probable difference in feeding value of various nitrogenous compounds. Amides have the structure of organic acids, into which amino groups have been substituted for the hydroxyl group of acid radicles. They are, as we might therefore expect, neutral, salt-like bodies. They require only the addition of one part of water to the molecule to become ammonium salts, and may be considered as derivatives of ammonia as well as of acids. Asparagin is an amide found in many plants, as in asparagus, peas and beans, especially just after sprouting. Glutamin, which has been found in squash seedlings and beet juice with asparagin, is also an amide. These are properly double amino compounds, being amides of amino-acids. They offer examples of the possible complexity of structure of organic nitrogenous compounds even in their simpler forms. The amides and amino-acids which occur at intermediate stages of the growth of plants, are derived from the disintegration of the seed proteins, or from constructive processes in the leaves and are to

a greater or less extent precursors of protein compounds in the new seed. Being readily soluble in water, they form ready means for the transportation in the sap of protein forming structures, and can be placed at the disposal of the reconstructive forces in the plant.

Amines, or compound ammonias, have only a limited practical importance as plant compounds. They are strongly basic compounds resulting from the replacement of hydrogen in ammonia by hydrocarbon radicles. The rank odor of some plants as the fetid goose foot and hawthorn is due to compounds of this sort.

Alkaloids are basic organic compounds involving substitution of more complex organic radicles into the ammonia molecule than is the case with the amines. By virtue of their basic structure they combine with acids; the salts so formed offer means of isolating and purifying these bodies. Some of the more common alkaloids are nicotine of tobacco; morphine of the poppy; strychnine, brucine and curarine of strychnos wood; quinine of cinchona bark; piperin of pepper; solanin of the potato and nightshade; and cocaine of the leaves of the South American cocoa tree. Some are of medicinal value as stimulants (strychnine), others act as narcotics (nicotine, morphine), and still others are virulent poisons (curarine, solanin). Curarine is the active constituent of curare extract with which some wild tribes poison their arrow-tips.

The ash constituents of the plant, usually relatively small in amount, are for the most part absolutely essential to its life activities. The following chemical elements are always found in plant ash: Calcium, potassium, magnesium, sodium, iron, phosphorus, sulphur, chlorine and silicon. Manganese and aluminum are occasionally present; and zinc, barium and other metals sometimes occur as accidental constituents.

The following brief table gives the amount and composition of the ash of some typical plants. The subject will be taken up more in detail in connection with the relative composition and food demands of crops.

Composition of the Ash of Plants.

Plant	Pure Ash per cent in dry plant	Ash Constituents. Per cent in the pure ash.								
		Pot-ash	Soda	Lime	Mag-nesia	Iron Oxide	Phos-phoric Acid	Sul-phur tri-oxide	Silica	Chlor-ine
Timothy (hay).....	6.82	34.69	1.83	8.05	3.24	0.83	11.80	2.85	32.17	5.19
Clover (early bloom)....	6.86	32.29	1.97	34.91	10.90	1.08	9.64	3.23	2.69	3.78
Wheat (grain)....	1.96	31.16	2.07	3.25	12.06	1.28	47.22	0.39	1.96	0.32
Wheat (straw)...	5.37	13.65	1.38	5.76	2.48	0.61	4.81	2.45	67.50	1.68
Oat (grain)...	3.12	17.90	1.66	3.60	7.13	1.18	25.64	1.78	39.18	0.94
Oat (straw)...	7.17	26.42	3.29	6.97	3.66	1.16	4.59	3.21	46.69	4.37
Potato (tuber)....	3.79	60.06	2.96	2.64	4.93	1.10	16.86	6.52	2.04	3.46
Sugar beet (root)....	3.83	53.13	8.92	6.08	7.86	1.14	12.18	4.20	2.28	4.81
Corn (grain)...	1.45	29.78	1.10	2.17	15.52	0.76	45.61	0.78	2.09	0.91
Corn (stalks)	5.33	36.30	1.20	10.80	5.70	2.30	8.30	5.30	28.80	1.40

The ash constituents of plants occurring in the seed are present there almost entirely as constituents of organic compounds. The hulls of the oat and other grains, which are not a part of the seed proper, have been found to contain considerable amounts of inorganic compounds, among which silica is especially notable. The large amount of this ingredient in cereal straws is supposed to be in inorganic form, and phosphorus and sulphur have been shown to be present in the stems of legumes and other plants at early stages of growth to a large extent as constituents of inorganic compounds. When the plant is burned, sulphur, phosphorus and other acid forming elements which are present in organic compounds, are converted to acid radicles. These acid radicles combine with basic radicles simultaneously formed from calcium, potassium and other metallic elements in the plant. This results in the production of inorganic salts, such as potas-

sium sulphate and calcium phosphate, in the ash. Any excess of the basic elements over the acid forming elements will combine with the carbonic acid present in the air as a result of the process of combustion, and will occur in the ash as carbonates. The large amount of potassium carbonate in wood ashes is formed in this manner. On the other hand, any excess of acid forming elements in the plant will be lost by volatilization and will fail to appear in the ash. It is thus evident that the composition of the ash gives little clue to the previous status of its constituents in the plant.

In some cases, as with corn grain, where the basic elements of the plant are low, a large part of the sulphur and chlorine may be lost during incineration. The following data from Fraps illustrates this point.

Loss of Plant Elements by Burning.

	<i>Sulphur</i>		<i>Chlorine</i>	
	Total per cent	Per cent determined from ash	Total per cent	Per cent determined from ash
Corn (seed).....	0.135	Trace	0.04	Trace
Peas (seed).....	0.186	0.03	0.008	0.005
Oats (seed).....	0.196	0.02	0.097	0.005
Cotton seed (meal).....	0.44	0.07	0.032	0.008
Tobacco (leaf).....	0.20	0.17	—	—
Peanuts (fruit).....	0.188	0.05	—	—
Timothy (hay).....			0.888	0.864

In timothy hay and the tobacco leaf, where these losses have been slight, the plants contain a high proportion of base forming elements. In the other plants tabulated above, a lack of basic constituents, together with a high percentage of phosphorus, prevents complete retention of the other acid forming elements during combustion. With corn, Fraps recovered, as an ash constituent, but one-fiftieth of the total sulphur in that grain.

Considerable knowledge has accumulated as to the *status* of these ash constituents in the plant. Their *functions*, however, are in many cases not clearly understood.

Calcium has already been referred to as a constituent of salts of organic acids. It occurs widely distributed in this form. Although essential to the plant and apparently playing an important part in the chemical changes of living cells, its specific function is unknown. In some cases it appears to be of advantage in forming insoluble salts of organic acids, such as calcium oxalate, thus preventing harmful accumulations of free acids in the plant. Loew is of the opinion that calcium-protein compounds exist in the organized parts of plant cells, from which the nucleus and the chlorophyll bodies are built up. He attributes the characteristic poisonous action of soluble oxalates to their power of depriving these compounds of their calcium, converting it into the insoluble oxalate. According to this view, calcium is particularly essential to the metabolic processes in plants.

Magnesium exceeds calcium in the amount present in seeds and, according to Loew, it is attended by phosphorus and favors the assimilation of the latter body by retaining it in the form of soluble compounds. In the same manner, its abundant supply in the seed favors easy assimilation of the reserve phosphorus of this organ by the seedling.

Potassium is of common occurrence as a constituent of the salts of organic acids. It has also been known for a long time that potassium is intimately connected with the formation of starch and sugar by plants. It is uniformly abundant in the ash of plants rich in these carbohydrates. The lodging of cereal grain plants has been attributed to lack of potassium. This theory is probably based upon the known stimulating effect of potassium on the formation of cellulose and the simpler carbohydrates in plant growth, since it has been shown that lodging is due in some cases to lack of cellulose compounds in the cell walls of the plant. Stoklasa has recently shown that potassium is a constituent of the chlorophyll of grasses. This investigator states that it is more

abundant in the chlorophyll structures than in other parts of the plant. Loew calls attention to the efficiency of potassium and its compounds in condensing certain aldehydes. He attributes to this element the function of condensation in the formation of carbohydrates and proteins.

Phosphorus is an essential constituent of the nucleins and nucleo-proteins around which the activities of the living plant cell are centered. This element is also a constituent of the active chlorophyll. It is thus seen to be an element with complex and most important functions. Phosphorous is also a constituent of lecithin, the chief function of which has been suggested to be that of receiving fatty acids into its molecule and passing them on in soluble form to the protoplasm of the seedling. It would thus serve as a carrier of fats, which furnish energy for the first growth of the plant.

Sodium has been shown to be dispensable with many kinds of plants. There is some evidence that sodium chloride or common salt favors the action of diastase and sodium may function in this way in the transformations of carbohydrates. A considerable amount of work, especially an extended series of plot experiments at the Rhode Island Experiment Station with various crops, has afforded evidence that sodium favors economical utilization of a low potassium supply, particularly when relatively more sodium enters the plant.

Sulphur is a constituent of all proteins. It forms from 0.4 to 4.0 per cent of these compounds. It is a constituent of other organic compounds known as iso-sulpho-cyanates or mustard oils, common to the mustard, turnip and other cruciferous plants. The function of these compounds is not known.

Iron is essential to green plants and lack of it produces a condition of chlorosis, in which the leaves become bleached. While chlorophyll does not contain iron, its action is absolutely dependent upon this element, small amounts of the latter being extremely effective. Iron is a constituent of organic compounds in the nuclei of plant cells.

Chlorine is found to a considerable extent in the ash of the mangel and other root crops. It exerts beneficial action in some cases when applied as a fertilizer in the form of the sodium salt. Nobbe found that buck-wheat failed to develop beyond the flowering stage when lacking a supply of chlorine, and that great accumulations of starch formed in parts of the stems of the plant under investigation. This has led to the view that chlorine, in the form of the sodium salt, is essential to the proper activity of diastase.

Silicon is abundant in many plants, such as the graminæ (grass family, which includes the cereal grains), equisetaceæ (horse tails) and the ironwood, cauto and other trees. Wicke found that the ash of the cauto tree contained 96 per cent of silica; and the ash of the common scouring rush (*Equisetum hyemale*) has been found to contain 97.5 per cent of this constituent. This element accumulates in the external tissues of the plant as a constituent of the inorganic compound, silica. Oats, and corn through three generations, have been matured on traces of silicon and this element has been considered generally as unessential to plants. There is considerable evidence, however, that this element favors economical utilization of small supplies of phosphorus by plants.

Of the occasional constituents of plant ash, *manganese* has been found to be an essential constituent of laccase, an enzyme in the sap of the lac-tree. It is to this enzyme that the setting of lacquer varnish is due, and its activity has been found to be proportional to the amount of manganese present. The ash of laccase contains as high as 2 per cent of manganese.

Aluminum occurs in some Lycopodiaceæ (club mosses) to the extent of 22 to 27 per cent of the ash. The recent work of Moseley on the occurrence of aluminum in certain plants is of great interest. He attributes to this element the cause of the disease known as "milk sickness" or "trembles," which may break out occasionally among dairy cattle and other animals. Moseley asserts that animals contract the disease when fed the white snake

root, which he showed contains aluminum phosphate. By the use of this salt he has reproduced the disease in smaller animals. The occurrence of the disease in the southern states has been traced to the same salt, but there occurring in the stems of the rayless golden rod. In fact, Moseley believes that wherever "trembles" prevails it is caused by aluminum phosphate, contained in such plants as the white snake root or rayless golden rod.

Alpine cress, grown where the soil contained over 20 per cent of zinc, was found to contain the following amounts of zinc, expressed as zinc oxide and in per cent of the total ash:

Roots	1.66 per cent
Stem	3.28 "
Leaf	13.12 "

Iodine occurs in marine algae to the extent of 0.06 per cent of the dry matter. This is of interest as evidence of the assimilating power of the plant, since sea water contains this element to the extent of only one part in four million.

Bromine also occurs in sea weeds. *Copper, lead* and other metals are sometimes found in plants growing upon soils which contain such elements.

Barium has been found in beech and birch trees and in wheat grown upon barium-containing soils. The presence of this element as an ash constituent of certain leguminous plants has been of considerable practical concern to ranchmen. It has been shown to be the active constituent of certain plants producing the loco-disease in animals. These "loco-weeds", as they are commonly called, have given trouble in Australia, and losses to stockmen from this cause on the United States plains have been heavy. The losses in Colorado alone have been estimated at a million dollars yearly. Loco-plants grown on some soils are non-poisonous and contain no barium. This is a case in which an accidental ash constituent has become of marked economic importance.

From all the evidence at hand, it appears probable that all the ash constituents normally present in plants have some func-

tion in the chemical processes of plant growth. In this connection the compound phytin is of interest. This is a complex salt containing potassium, calcium and magnesium in combination with an organic, phosphorus-bearing acid. It has been isolated from a number of seeds, including the common cereals, where it represents a concentrated form of storage of ash constituents for the embryonic plant. Phytin may influence the feeding value of these seeds and their products. It contains practically all the phosphorus, magnesium and potassium occurring in wheat bran and gives to that dairy feed its laxative properties.

CHAPTER VI

FARM MANURE

For a soil to possess fertility, that is, to be able to properly support the growth of plants, certain conditions are necessary. The following may be mentioned as being perhaps the most important.

(1) Its mechanical or physical condition must be suitable.

(2) It must contain sufficient plant food in a form which is readily available to the crop.

(3) It must not contain any appreciable quantity of poisonous or injurious substances.

(4) It must not contain injurious insects, fungi or other organisms which are destructive to crops.

(5) The temperature, sunshine, rainfall and other climatic conditions must be suitable.

Of these the second and third and to some extent the first, are matters in which chemistry may be of service.

Every crop removed from the soil robs it of materials which have been used in building up the plant's tissues. Soil which annually bears a crop must in time become exhausted of its store of plant food and unfitted to bear further crops. Often one constituent of plant food becomes exhausted first and in many cases restoration of this constituent would renew the fertility for some time longer. Substances which are added to the soil in order to replace the ingredients which have been removed by previous crops are called *manures*.

All constituents of plants present in a soil, except the carbon, are diminished by the growth of crops upon it, but the substances which usually first become deficient are combined nitrogen, and available phosphorus, calcium, potassium and possibly sulphur. Consequently manures are valued according to the quantities of these ingredients present in them, although in many cases the

other constituents may exert an important influence upon the soil.

Barnyard manure. Of all fertilizers, barnyard manure is the oldest and still the most popular. It consists of the liquid and solid excreta of the farm stock, plus the litter employed. Early Roman writers called attention to the fact that the application of the excreta of farm animals resulted in increased production. and from that time to the present the majority of farmers have placed their reliance on this class of manures for maintaining the fertility of the land.

A well kept manure heap may safely be taken as one of the surest indications of thrift and success in farming. Neglect of this resource causes losses which, though little appreciated, are vast in extent. "Waste of manure is either so common as to breed indifference, or so silent as to escape notice. According to recent statistics there are in the United States in round numbers, 19,500,000 horses, mules, etc., 61,000,000 cattle, 47,000,000 hogs and 51,600,000 sheep. Experiments indicate that if these animals were kept in stalls or pens throughout the year and the manure carefully saved, the approximate value of the fertilizing constituents of the manure produced by each horse or mule annually would be \$27, by each head of cattle \$20, by each hog \$8, and by each sheep \$2. The fertilizing value of the manure produced by the different classes of farm animals in the United States, would therefore be for horses, mules, etc., \$526,500,000; cattle \$1,220,000,000; hogs, \$376,000,000, and sheep, \$103,200,000, or a total of \$2,225,700,000. These estimates are based on the values usually assigned to phosphoric acid, potash and nitrogen in commercial fertilizers, and are possibly somewhat too high from a practical standpoint. On the other hand it must be borne in mind that no account is taken of the value of manure for improving the mechanical condition and drainage of soils, which is fully as important a consideration as its direct fertilizing value."

It is fair to assume that at least one-third of the value of the manure is annually lost through careless methods of manage-

ment. And this estimate is conservative. Even at this figure we have the tremendous sum of \$750,900,000 as an annual loss in the United States. This condition is the more unfortunate because practically all of it could be prevented.

In Wisconsin the value of the manure produced annually by its 1,300,000 milch cows, 1,100,000 other cattle, 600,000 horses, 1,000,000 sheep and 1,900,000 swine, based on the above figures, is approximately \$60,000,000. And it is also true that as large a proportion of its valuable constituents is annually lost as in any part of the United States. It is safe to say that from the farms of Wisconsin there is an annual loss of at least \$20,000,000 from the indifferent and careless management of the manure produced.

Composition of manure from different animals. The manure produced by the various classes of farm animals differs greatly in its composition and physical properties. The following table gives the average composition of the fresh manure (including solid and liquid excrement) of farm animals. It will be seen from the table that the differences in composition are largely due to the variations in the amount of water present:—

Average Composition of Fresh Manures.

Animal	Water	Nitrogen	Phos. Acid	Potash	Value per ton
	Per cent	Per cent	Per cent	Per cent	Dollars
Sheep	64.0	0.83	0.23	0.67	3.39
Horse	70.0	0.58	0.28	0.53	2.55
Pig	73.0	0.45	0.19	0.60	2.14
Cow	77.0	0.44	0.16	0.40	1.89
Mixed	75.9	0.45	0.21	0.52	2.08

A ton of mixed manure of average composition contains approximately 5 pounds of phosphoric acid, 10 pounds of nitrogen and 10 pounds of potash.

Manures containing large amounts of water are "cold ma-

nures;" that is, they are manures which heat slowly because the high water content checks fermentations. Sheep and horse manure are known as "hot manures," due to a lower water content which is favorable to a more rapid fermentation.

Amount and value of manure from different animals. It is sometimes important for the farmer to know the total amount and value of the manure produced in a year by the different farm animals. In the following table such data are brought together, with the amount of manure calculated to the same live weight of the various animals.

Amount and Value of Manure per 1000 lbs. of Live Weight of Different Animals.

	Amount per day	Value per day	Value per year
	Pounds	Cents	Dollars
Sheep	34.1	7.2	26.09
Calves	67.8	6.7	24.45
Hogs	56.2	10.4	37.96
Cows	74.1	8.0	29.27
Horses	48.8	7.6	27.74

If these figures are accepted as representing normal conditions, it follows that the sum of thirty dollars may be taken as representing the average value of the fresh manure from each 1000 pounds of live weight. The use of this factor (thirty dollars per 1000 pounds) will enable the student to calculate approximately what the nitrogen, phosphoric acid and potash in the manure produced on his farm would cost,* if purchased in commercial fertilizers, granting of course that the manure is so managed as to prevent loss of its valuable constituents.

*All the valuations in the calculations made are based on 15 cents per pound for nitrogen and 5 cents per pound for phosphoric acid and for potash. This represents in round numbers the market price of these ingredients in commercial fertilizers at the present time.

Factors which influence the composition of manure. The composition of the excrement varies greatly, dependent on the following factors:

- (1) The character of the ration.
- (2) Age and kind of animal.
- (3) Kind and amount of absorbents used.

Considerable variation in the composition of the excreta of various animals must necessarily be expected.

Influence of the ration. The total value of the manure produced by a given number of animals is dependent on the quality and quantity of the feeding stuffs used in the ration. That the different materials used for feeding vary greatly in their fertilizing value is clearly shown in the following table, which gives the quantity of fertilizing materials in one ton of a few of the common feeding stuffs and farm products. Additional figures are to be found in a table of the appendix:—

Pounds of Fertilizing Constituents in One Ton.

	Nitrogen	Phosphoric Acid	Potash	Value per ton
	Lbs.	Lbs.	Lbs.	Dollars
Wheat straw.....	11.8	2.4	10.2	2.40
Corn Silage.....	5.6	2.2	7.4	1.32
Clover hay.....	41.4	7.6	44.0	8.79
Wheat bran.....	53.4	57.8	32.2	12.52
Linseed meal.....	108.6	33.2	27.4	19.22
Oats.....	41.2	16.4	12.4	7.62
Milk.....	10.0	3.0	3.0	1.80
Butter.....	2.0	1.0	1.0	0.40
Pigs (live).....	40.0	17.0	3.0	5.00

The figures represent the fertilizing values of the different feeds, provided they are used directly as manures. It is clear that the richer the ration is in nitrogen, phosphoric acid and potash, the more valuable will be the manure produced by the animal. It is necessary now to inquire what proportion of the fertilizing content of the food is recovered in the excrement.

Influence of age and kind of animal. If a mature animal, as a steer, for example, is confined in such a manner that all the excrement, both liquid and solid, can be preserved, it will be found that all the nitrogen, phosphoric acid and potash of the food will be contained in the excreta. This is when the animal is not gaining in weight. None of these constituents will be stored in the tissues, but all are voided in the dung and urine. On the other hand, only about half of the total dry matter of the ration will be voided in the excrement, a large part of the other half having been given off from the lungs as carbon dioxide. While the excreta, therefore, contain only about half of the total dry matter which was present in the ration, they contain all the constituents that are generally considered of fertilizing value.

With young growing animals, gaining in weight, the above statement is incorrect. They retain a certain proportion of the nitrogen, potash and phosphoric acid for use in building up their bodies. The amount retained depends upon the age of the animal and its rate of growth. Experiments indicate that calves retain during the first three months of their lives about one-third of the fertilizing value of the food consumed, while the other two-thirds would be found in the excrement. For the first year of their existence they use in growth about one-fifth of the nitrogen, phosphoric acid and potash present in the food and as the animal ages, the amount gradually diminishes until practically none of these materials are retained. When a mature animal is fattening there is practically no drain on the fertilizing value of the feed, provided the gain is all fat. This is due to the fact that fat contains only carbon, hydrogen and oxygen, and consequently its production does not remove any of the fertilizing constituents.

The above deductions are equally applicable to the other classes of farm animals, such as swine, sheep and horses, and the age of the animal has the same effect on the value of the manure.

Influence of milk production. In the case of the cow another factor is introduced, as a certain proportion of the nitrogen, phosphoric acid and potash is removed in the milk. One hundred

pounds of milk contain on an average about 0.53 pound of nitrogen, 0.19 pound of phosphoric acid and 0.17 pound of potash. An annual yield of five thousand pounds, therefore, removes in the milk fertilizing material amounting in value to \$4.90. If the milk is sold, this is lost to the farm. Where butter is made and sold, practically none is carried away, as all the valuable ingredients are left in the skimmed milk. The fertilizing value of 500 pounds of butter amounts to about ten cents. Even when the milk is sold, fully 85 per cent of the manurial value of the food is recovered.

Eighty per cent of plant food recovered in manure. Taking into account the relation between matured and young stock, milk-producing and non-milk-producing animals, as found on the average farm, it is conservative to assume that at least 80 per cent of all the fertilizing constituents present in the materials fed on the farm, is voided by the animals in the solid and liquid excreta. This includes the amount removed in the milk, that retained by the young animals during their growing period, and consequently, the fertility removed from the farm by the sale of animals grown thereon. The fertilizing value of the excrement produced from one ton of feeding material is therefore readily ascertained by taking 80 per cent of the fertilizing value therein stated. From this it will readily be seen that the composition of the feeding stuff really determines the value of the excrement. The manure (combined solid and liquid excrement) from one ton of wheat straw would be worth \$1.92, while that from one ton of corn meal, wheat bran, or linseed meal, would be worth \$5.24, \$10.01, and \$15.37 respectively.

Reference to the table will show that in most cases the amount of nitrogen is the factor determining the fertilizing value of a feeding stuff. This is due to the fact that nitrogen is usually present in larger proportion than phosphoric acid or potash, and is much more costly when purchased. Wheat bran and linseed meal, however, are particularly rich in both phosphoric acid and potash.

Effect of bedding on value of manure. Barn yard manure, as the term is generally used, includes in addition to the excreta, the litter or bedding used to absorb the urine. The following table gives the composition of some of the materials used for bedding:—

Fertilizing Constituents in One Ton of Litter.

	Nitrogen	Phosphoric Acid	Potash
	Lbs.	Lbs.	Lbs.
Wheat straw.	11.8	2.4	10.2
Oat straw.....	12.4	4.0	24.8
Clover straw	29.4	8.4	25.2
Saw dust.....	4 0	6.0	14.0
Peat.....	20.0	...	....

The richer the bedding the more valuable will be the manure. The materials commonly used for bedding are low in the elements of fertility, so that the use of large amounts decreases the worth per ton of the manure, but in any case sufficient litter should be used to absorb all the liquid excrement.

Calculating the amount of manure from the ration. The total weight of manure that will be produced from the material fed an animal can be calculated with considerable accuracy. Experiments have shown that about 50 per cent of the dry matter present in the ration is recovered in the excrement. The least amount of bedding that will absorb all urine excreted must contain dry matter equal to 25 per cent of the dry matter in the feeds used; consequently if just enough bedding is used, the manure (excrement plus bedding) contains 75 per cent of the dry matter in the ration. Since mixed farm manure contains on an average 75 per cent of water, or 25 per cent of dry matter, the 75 per cent of dry matter mentioned above must be multiplied by four to find the total manure. This gives a result of 300 per cent of the dry matter in the ration for the weight of the manure. In other words if we multiply the dry matter of the ration by *three*, we will have a close approximation to the weight of the

manure produced. This method of calculating holds true only when the theoretical quantity of bedding has been used.

In practice the farmer usually uses all the bedding material he has at hand, even if it may exceed that necessary to absorb all the urine, and such practice is generally considered advisable for the reason that such materials as straw or shavings will decay much more readily when mixed with the excrement of animals. Where more litter than the theoretical amount is used, the method of calculation given must be corrected by adding to the total, the weight of the bedding in excess of 25 per cent of the dry matter of the ration.

Value of manure. The great importance of barn yard manure as a farm resource is appreciated to its full extent by but few farmers. A large proportion of those engaged in agricultural pursuits seem to have little realization of the immense loss incurred through the waste of this important product of the farm. They begrudge the time and labor required to remove it from the barn and feeding lot and it is not uncommon to see the purchase of commercial fertilizers and the waste of farm manure going on at the same time and on the same farm. Barns are erected on steep hillsides, or even close to the banks of running streams, which practice insures a most effective and wasteful loss of the valuable constituents of the manure heap.

In order to fully emphasize the great value of the manure produced on the farm, figures are given for the amount and value of the manure produced in one year by a herd of 50 cows giving an average individual yield of 15 pounds of milk daily. These results are largely taken from Vivian's "First Principles of Soil Fertility."

It is assumed that the same ration is fed throughout the year. In actual practice the ration varies somewhat throughout the year, but nevertheless the good feeder aims to keep the composition of the ration very much the same even when various sources of food materials are drawn upon.

The following ration will be used as a basis for calculation,

with the daily consumption for a cow weighing 1,000 pounds and giving 15 pounds of milk; 10 pounds of a mixture of one-third each of corn meal, ground oats and bran; 35 pounds of corn silage; 15 pounds of clover hay (medium red). This is a good practical ration and conforms well with the best feeding standards. It will be assumed that just the amount of wheat straw which would theoretically be necessary to absorb the liquid excrement is used as bedding. Allowance for milk production is of course made by using the factor of 80 per cent as the basis for calculating the amounts of fertilizing material recovered in the excrement from the total contained in the feeds.

Fertilizing Constituents of the Manure.

	Nitrogen	Phosphoric Acid	Potash
	Lbs.	Lbs.	Lbs.
In excrement.....	8958.47	3483.50	7982.77
In bedding.....	742.61	340.22	974.28
Totals	9701.08	3823.72	8957.05

The prices paid for fertilizing materials at the present time are 15 cents per pound for nitrogen and 5 cents each for phosphoric acid and potash. These prices hold only when raw materials are bought, and much higher prices are paid for mixed fertilizers. From these prices is calculated the total value of the manure produced by 50 cows in one year:

Value of Manure for Fifty Cows.

Value of nitrogen.....	\$1455.18
Value of phosphoric acid.....	191.19
Value of potash.....	447.85
Total value of manure.....	\$2094.22

This means that the fresh manure from 50 cows contains amounts of nitrogen, phosphoric acid and potash that would cost the farmer at least \$2094.22 if purchased in commercial fertil-

izers. The amount of manure produced would weight 811.9 tons, giving a value of \$2.58 for each ton. How near the actual agricultural value of the manure will approach the trade value will depend upon a number of conditions, such as crop to be fed, physical condition of the soil, climate, and especially the management of the manure itself. The same statement applies to commercial fertilizers, the trade price being no indication of the agricultural value of the material, and the farmer who profits most from the use of commercial fertilizers is also the one to be best repaid for the use of barn yard manure. In experiments conducted at the Ohio Experiment Station and covering a period of ten years, it was found that the average value of the increase of crop produced by one ton of fresh manure amounted to \$3.44. If 50 cents per ton be allowed, as the cost of applying the manure to the field, there still remains a substantial profit, as the result of the application.

How to increase the value of manure. Where a system of animal husbandry is practiced, the farmer will find that the most economical way to increase the plant food for the farm is by purchasing feeding stuffs rich in fertilizing constituents, feeding them to the animals and using the manure as a fertilizer. In a system of grain farming he will, of course, be obliged to supply his deficiency in plant food by direct purchase of the needed elements in the form of commercial fertilizers. The successful stockman finds it profitable to reinforce the feeds raised on the farm with one or more of the various mill and other by-products that are sold as cattle feeds. A farmer who buys large quantities of concentrates is increasing the fertility of his land provided he is taking proper care of the manure. At the University Farm there is an annual gain in fertilizer elements from purchased feeding stuffs over the losses sustained by the sale of animals and animal products.

In purchasing feeding stuffs, one should always consider their fertilizing value, as well as their feeding value, for, while the substance is bought primarily to feed, it is sometimes possible to

buy different materials which will serve practically the same as feeds and yet vary greatly in their value as fertilizers. It is indeed often sane practice to sell some of the products produced on the farm and with the money thus obtained purchase other feeding materials. There is scarcely a farm on which such an exchange could not be made to advantage.

The following example will illustrate more clearly what is meant. At the time of writing it was possible to buy on the local market 6.4 tons of clover hay for the price of 5 tons of timothy hay, and 5 tons of corn could have been exchanged for 4.6 tons of wheat bran. Calculating the value of fertilizing materials in the manner already described, the results are as follows:

Fertilizing value of 6.4 tons of clover.....	\$ 48.55
Fertilizing value of 4.6 tons of bran.....	57.32
Total.....	\$105.87
Fertilizing value of 5 tons of timothy.....	\$ 23.00
Fertilizing value of 5 tons of corn.....	28.50
Total.....	\$ 51.50
Gain due to exchange.....	\$ 54.37

By a simple exchange of products without any cash outlay the fertilizing value of the ration has been increased \$54.37 and consequently the manure produced would have been worth \$43.49 more than that resulting from the use of corn and timothy hay. This example is offered merely as a suggestion, which may be made of considerable practical value, dependent on the market prices of the various feeds.

In the above example the actual feeding value has been increased in the exchange due to the increase in protein in both clover and bran, with no decrease but rather an actual gain in the dry matter purchased.

Losses in manure. Barn yard manure is a perishable product and must be handled with intelligence to obtain its maximum value. Doubtless as manure is handled on the majority of farms,

only one-half of its worth is realized. The greatest loss is through the waste of the liquid excrement by the use of insufficient bedding to absorb it. The boring of holes in the floor for the express purpose of allowing the urine to run off as rapidly as possible is by no means an uncommon practice. The following table gives the composition of the solid and liquid excrement:

Percentage of Fertilizing Constituents in Solid and Liquid Excrements

	Nitrogen		Phosphoric Acid		Soda and Potash	
	Solid	Liquid	Solid	Liquid	Solid	Liquid
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Horses	.50	1.20	0.35	Trace	0.30	1.50
Cows	.30	0.80	0.25	Trace	0.10	1.40
Swine	.60	0.30	0.45	0.12	0.50	0.20
Sheep	.75	1.40	0.60	0.05	0.30	2.00

Pound for pound the liquid excrement is more valuable than the solid, except in the case of swine. It is perfectly safe to say that of the total fertilizing material in the manure, two-thirds of the nitrogen, four-fifths of the potash, and practically none of the phosphoric acid, are found in the urine. It is apparent that somewhat over half of the total value of the manure is in the urine. Had the liquid portion of the manure been allowed to run away, the value of the excrement as calculated in the example given above would have been less than \$1000 instead of \$2049.

Another fact of great importance in this connection is that the plant food in the urine is in a form that is soluble in water and consequently more available to plants than that in the solid dung. This is particularly true of the nitrogen. The solid excrement consists in part of the undigested portion of the food, and before its nitrogen can become available to plants, it must undergo decomposition and decay.

The difference in value of the solid and liquid excrement is

well brought out in the following experiment from the New Jersey Experiment Station. Two plots were treated with manure, the one receiving only solid excrement, while on the other the mixed solid and liquid excrement was used. Each plot received enough of the manure to supply equal quantities of nitrogen. The results are stated in percentage of gain over a check plot that received no manure.

Percentage of Gain in Yield from Manure.

	Solid excrement only	Solid and liquid excrement
First year.....	15.2	52.7
Second year.....	69.7	116.9
Third year.....	47.9	80.6
Average.....	44.3	83.4

The table clearly shows that the yield from the same amount of nitrogen was very much larger from the mixed manure than from the solid excrement alone. The experiment also indicates that the nitrogen in the liquid excrement was much more readily utilized by the plant than that in the solid excrement.

Manure is never so valuable as when fresh; and the very best methods of handling and care, if the manure must be stored, cannot prevent some loss of the valuable constituents. For this reason, it is advisable when possible, to apply manure to the field as fast as it is made.

Losses in manure from leaching. In addition to the great losses due to improper absorption of the urine, the manure suffers heavily from leaching by rains. This is probably the greatest source of loss. It is often allowed to lie for months in the open barn yard, or better, directly under the eaves of the barn, where the leaching and washing processes are more complete. Even after plenty of litter has been used and all urine absorbed, it is

not uncommon to see it placed where it is directly exposed to the continuous action of the elements.

At the New Jersey Experiment Station four samples of manure were exposed to the weather for varying lengths of time and the losses determined. The results are given in the following table:

Losses in Manure from Leaching.

Period in days	Nitrogen	Phosphoric Acid	Potash
	Per cent	Per cent	Per cent
131	57.0	62.0	72.0
70	44.0	16.0	28.0
76	39.0	63.0	56.0
50	69.0	59.0	72.0
Average	51.0	51.1	61.1

The average loss amounted to more than 50 per cent of the value of the manure during rather short periods. It is very common, if not the rule, to find manure exposed on many farms for longer periods than here shown. The aggregate loss of the plant food of the country by such exposure is appalling. Experiments at the Cornell Experiment Station with manure exposed to the weather for a period of five months (April to September) gave the following data:—

	Value at beginning per ton	Loss per ton	Loss per cent
Horse manure.....	\$2.80	\$1.74	62.0
Cow manure.....	2.29	0.69	30.0

It is necessary to state that the losses will vary with climatic conditions. During heavy rain in warm weather, the losses will be heavier than in dry or cold weather.

Losses from solid excrement by leaching. Not only is the liquid portion of the excreta of the animal lost by exposure to

leaching, but in addition, the solid excrement suffers loss. A considerable portion of both the phosphoric acid and potash eliminated through the intestine is in a soluble form, and the



Manure leaching. How the manure in America is wasted.

chemical changes constantly going on in a manure pile are making soluble the insoluble nitrogenous portions of the dung.

The following table illustrates the losses which may occur when the solid excrement alone is exposed for varying lengths of time.

Losses in Solid Excrement from Leaching.

Period in days	Nitrogen	Phosphoric Acid	Potash
	Per cent	Per cent	Per cent
131	46.0	72.0	80.0
70	34.0	27.0	10.0
76	25.0	54.0	48.0
50	45.0	42.0	42.0
Average	37.6	51.9	47.1

In addition to the actual losses taking place, the character of the material lost is of considerable importance. The nitrogen in the portion removed by leaching, is more valuable, pound for pound, than that remaining, because it is in a form more immediately available to the crop.

In an experiment at the New Jersey Experiment Station two plots were treated with quantities of fresh and leached manure, both containing exactly the same amounts of nitrogen. The results are tabulated below and are stated in percentage of gain over a plot receiving no manure.

Per cent of Gain in Yield from Manure.

	Fresh Manure	Leached Manure
First year.....	52.7	41.5
Second year.....	108.4	96.8
Third year.....	187.5	89.6
Average.....	116.9	76.0

The common practice of open yard feeding, where the manure produced during the winter is spread over a considerable area and often allowed to remain until late spring, or even into the fall, is most wasteful of the fertilizing material it contains. It is safe to say that at least one-half of the fertilizing value of the manure is lost by such practice. This method of feeding is extremely common and in the corn belt of this country it is not unusual to see a large feeding yard covered to a considerable depth with manure, under ideal conditions for maximum leaching.

Losses by fermentation. Manure is very easily decomposed and the losses resulting from such decomposition fall entirely on the most valuable constituent of the manure, the nitrogen. Through the process of fermentation no potash or phosphoric acid is lost. These manurial ingredients are wasted only through leaching.

The first evidence of fermentation is the odor of ammonia. This is noticeable in the barn, especially if it has been closed during the night. It is due to the rapid decomposition of urea, the principal nitrogenous body of the urine. Ammonia contains nitrogen and when its presence is noticed, it is evident that nitrogen is escaping into the air. It is impossible to entirely prevent the formation of ammonia from the urea, but it is possible to greatly reduce its loss by providing plenty of absorbing material and keeping the manure moist.

The fermentation of manure is due to different kinds of bacteria. Some of these can exist only in the presence of air and are called "aerobic," while others do not require free air and are classified as "anaerobic." The aerobic organisms are responsible for the hot fermentation which is the cause of great loss of value in manure. It is well known that when manure is thrown into loose heaps and contains a large proportion of horse or sheep excrement it soon becomes very hot and dry, in fact, hot enough to steam, and the temperature may reach 175° Fahr. In this condition the common "fire fanging," or burning white in spots, takes place, and heavy losses of nitrogen are sure to occur. Experiments have shown losses of from 30 to 80 per cent of the nitrogen. In extreme cases of fire-fanging all the nitrogen will be lost.

If the manure heap is so compact that the air cannot penetrate it, the aerobic bacteria are unable to live, and hence hot fermentation is prevented. Where aerobic bacteria are active the soluble forms of nitrogen in the manure are partly converted into nitrates and these in turn may be attacked by certain anaerobic bacteria called "denitrifiers," which liberate elemental or free nitrogen from such compounds. This is an additional reason for checking, so far as possible, all aerobic fermentations. The presence of large quantities of water in the manure heap holds the temperature down, displaces the air and in this way checks aerobic fermentations. For this reason, the moist cow and pig excrements are not so subject to hot fermentation as that of the

horse or sheep. This explains the sound practice of mixing the manure from the various classes of farm animals, when it is necessary that it be stored.

When the manure is in a compact mass and moist the fermentations that take place are due to anaerobic bacteria. These fermentations convert the insoluble plant food in the excrement into soluble forms, with little loss of the fertilizing constituents. Under the best conditions of care, it is impossible to entirely prevent losses in stored manure, although if properly preserved it may be reduced to about 10 per cent of the nitrogen and none of the other two fertilizing constituents.

Preservation of manure. Saving the urine. From all that has been said it must appear perfectly plain that one of the greatest losses suffered by the farm is through failure to save the liquid excrement of the animal. To insure against such loss, that part of the barn floor on which the excrement falls must be so tight that none of the liquid can drain away.

The trough behind the animals should be made absolutely tight by the use of pitch, cement, or some other material that is impervious to water. Besides this precaution, enough litter should be used so that all urine is absorbed and none runs away by dripping, when the manure is removed from the barn. It is often of the greatest advantage to finely cut the bedding material. This increases its absorbing capacity, and facilitates handling the manure. Straw cut in one inch lengths, for example, will absorb about three times as much urine as long straw.

Stockmen who have practiced cutting the bedding assert that the great ease with which the manure will be removed and spread will repay the cost and trouble, to say nothing of the saving of bedding materials.

Use of preservatives. As has been previously explained, the urine of all farm animals contains its nitrogen principally in the compound known as urea. This body is rapidly and readily decomposed by ferments and changes into ammonium carbonate. This latter substance is volatile and passes off into the air, where

it can be detected by the sense of smell, that is, by the odor of ammonia. The dry manures, as those of the horse and sheep, are particularly subject to this loss of nitrogen, which is contained in the escaping ammonia. Many from the farm have suffered with "smarting eyes" when removing the accumulated manure from the horse stable. This is due to the ammonia and can be prevented partly by the use of land plaster or gypsum. This fixes the ammonia in part, by forming ammonium sulphate, which is a non-volatile body. In using gypsum scatter it on the floor immediately after the barn has been cleaned and before the fresh bedding has been spread. From one-half to one pound per animal each day is used in common practice. It is not impossible that part of the beneficial results obtained by adding gypsum in the manure and to the land comes from the additional supply of sulphur.

Other preservatives, as kainite, muriate of potash and acid phosphate, are often recommended as preservatives for manure and to prevent the loss of nitrogen. They are reported to be injurious to the hoofs of animals and when used should be scattered on the floor and carefully covered with bedding. There is much difference of opinion as to their merits as preservatives, but unquestionably they all can effect a partial retention of escaping ammonia and thus act as "barn-sweeteners." They will also serve the additional function of reinforcing the manure with fertilizing materials. They may be used in the same quantity as recommended for gypsum. Dry earth has been recommended for the same purpose and is especially useful in this regard, particularly where it contains a large amount of humus. In some parts of the country dry peat or muck soil is in use in the stable in connection with the bedding. It should never be used in quantities sufficient to make the manure dry, as this would result in still greater nitrogen losses.

Haul the manure when fresh. Manure is never so valuable as when perfectly fresh, for it is impossible under the best system of management to prevent all loss of its fertilizing ingredients. For

this reason it is recommended that wherever possible, the manure should be hauled directly to the field and spread. It is the most economical of time and labor, as it involves handling but once. While it is true that it will be leached by the rain, nevertheless, the soluble portion will be carried into the soil, where it is desired to have it. When spread in a thin layer, it will not heat, so there will be no loss from "hot fermentation;" and where manure simply dries out when spread on the ground, there is no loss of valuable constituents.

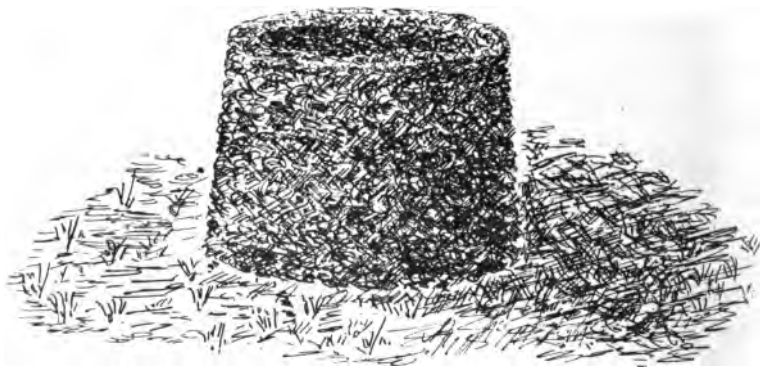


Wherever possible, haul and spread the manure daily as produced.

Storing manure. When it is impossible to remove the manure directly to the field, due to weather conditions or lack of available fields, the problem of properly storing it will present itself. From what has already been said, it is apparent that the two injurious processes, namely leaching and hot fermentation, must be prevented. The effect of leaching may be prevented in two ways; either by providing water tight receptacles so that the liquid cannot run away, or by keeping the manure under cover so as to protect it from the rains. The first method is in general use in Europe, where pits or cisterns of cement or other impervious material are built and in which the manure is stored. Sometimes a pump is provided, whereby the liquid portion is again

pumped over the more solid portion, keeping it moist and furthering decay with minimum loss. This process makes excellent manure but requires time and labor. The more economical way for the American farmer to prevent leaching, when manure must be stored, is to keep it under cover. A cheap lean-to or shed is all that is needed. Where it is possible, a water-tight floor should be provided.

Where neither cement cistern nor covered shed is available, and it becomes absolutely necessary to store the manure, the heap



When the manure must be stored and there is no cover, build the pile as shown above.

should be made so high and compact that the hardest rain will not soak through. The sides should be perpendicular and the top dipped toward the center. It is advantageous to have the manure saturated with water, but large losses of plant food would result should the water drain away from the heap.

Hot fermentation can be controlled by keeping the manure pile moist and compact. These two conditions exclude the air from the pile and prevent the action of that class of bacteria which causes hot fermentation and in addition, require free oxygen for their activity. When the heap shows a tendency to dry out, water should be added and each daily addition of manure to the pile firmly packed into place. This allows decomposition to con-

tinue, liberating the more insoluble plant food from organic constituents of the manure and greatly improving its mechanical condition. Mixing the manure from the various farm animals is the very best practice. The drier horse and sheep manure are checked in their fermentation by the more moist pig and cow excrements. When it becomes necessary to store the manure for some time, it is recommended to cover the heap with an inch or two of earth. This prevents the escape of any ammonia that may be formed.

Covered sheds save manure. Professor Roberts, formerly of Cornell University, was a strong advocate of covered barn yards for the conservation of manure. They are simply sheds, with good roofs, with or without sides and large enough to allow the cattle to freely move about. The bottom is made tight by puddling clay or using cement. The manure, as removed from the barn, is spread about and sufficient bedding distributed over the surface to insure cleanliness. The animals trample the accumulating manure into a compact mass and keep it moist by their liquid excrement. This insures an excellent manure, with but slight losses of plant food. In addition, it affords exercise and a healthful environment for the animals in severe weather. The plan has been tried by many dairymen and is generally considered very satisfactory. It is said that the cows keep cleaner than when stabled and that the milking barn is in a more sanitary condition.

The throwing of cattle and horse manure into basement rooms to be worked over by the hogs, is from the standpoint of the conservation of plant food, an economical process. By tramping and working over the manure, and by adding their own excrement, the mass is kept moist and fermentation controlled.

Deep stall manure. In some parts of Europe the "deep stall method" of saving manure is in vogue. It consists in excavating the stalls where the cattle stand to some depth below the barn floor level. Every day the manure is spread evenly over the stall and fresh bedding added. The excrement and bedding are firmly

packed by the feet of the animal and allowed to remain throughout the winter. The manure produced is of excellent quality, but for sanitary reasons the practice is hardly commendable, especially in the case of dairy cows.

Composting manure. Where well rotted manure is desired, as in market gardening, the practice of composting is in general use. This is largely done to avoid the deleterious heating effect that would result from applying large quantities of raw manure. In addition it is sometimes resorted to in order to destroy noxious weed seeds. A favorite method with some market gardeners is to compost the manure with earth, peat, or muck. This is done by making a foundation of about 6 inches of dirt, and on top of this placing alternate layers of manure and soil, moistening the mass as the heap grows. The mass is finally covered with a thin layer of earth to prevent loss of nitrogen. After about 2 months the pile should be turned over, the materials well mixed and more water added, if necessary, to keep the compost moist. Sometimes sod is used in place of the soil, which gives a fibrous compost very desirable for pot and bench work. Refuse materials, such as kitchen waste, dead animals, etc., can be added with advantage to the compost heap, thereby enriching the mass and disposing of such materials without the production of offensive odors. Where further enrichment is necessary, it is good practice to add bone meal or rock phosphate (floats) and one of the potash salts to the heap. In this way the plant food in the phosphates is made more available to plants and the compost more valuable.

When it is desired to produce well rotted manure in a very short time, a small quantity of slaked lime can be mixed with the fresh manure. This occasions a rapid decay of the mass, but as it also entails a loss of more or less nitrogen, the method is not to be recommended for general use.

Applying manure. A manure can be effective only when its constituents are brought into contact with the roots of the crop. To obtain this contact to its fullest extent, the manure must be thoroughly and evenly distributed throughout the depth of the

soil mainly occupied by the roots. For this reason it appears best, when possible, to apply the fertilizers to the surface as a top dressing, in order that the soluble plant food as it descends may come in contact with the plant roots. The manure to be used this way must be fine or well rotted, but even fresh manure can be so utilized where cut straw or other fine material has been used for bedding. The practice of applying the manure directly after plowing and thoroughly incorporating it with the soil by the use of the harrow or cultivator is a good one.

Spreading the manure and allowing it to lie on the surface



A poor way of using good manure.

should be practiced only on level fields where there is no danger from surface washing. It has been claimed that when manure is spread broadcast and allowed to lie on the surface, there may be serious loss of ammonia into the air, but experiments have shown that loss from this cause must be very small. Manure made during the winter and hauled directly to the field and spread on areas that are fairly level, whether fall plowed or on sod to be turned under in the spring, is most economical of labor and conserves most efficiently the valuable fertilizing materials. It may even be spread on the snow, where it is not too deep, without serious loss. The loss is certainly less than when thrown in the open barn yard.

Manure should be spread. The very common practice of hauling manure to the field, there to be thrown into heaps, has several serious objections. In the first place it increases the work entailed in spreading, as it must be handled twice. When

manure is so piled there is danger of injurious fermentations, with consequent losses of nitrogen. In addition, the leaching from such piles increases the amount of plant food directly beneath and hence produces a rank growth. It is not uncommon to find the next season's crop spotted by a more luxuriant growth and deeper green color on the areas where the manure heaps have been placed. This condition is highly undesirable, as it causes the crop to mature at different ages and also endangers loss by lodging. A crop with a large plant-food supply will have a



Uneven grain and grass. This bad condition comes from leaving the manure in small piles. It should be spread when hauled.

longer season of growth than one with a meagre supply. If the manure is spread directly from the wagon, the danger of unevenness of growth is largely avoided and the cost of labor reduced. When very coarse manure is used, it is advantageous to supplement the spreading from the wagon by the use of a drag that will break up the larger lumps and thus spread it more uniformly.

Depth to cover manure. Where the manure is so coarse as to interfere with tillage, it will become necessary to plow it under. Judgment must be exercised as to the depth to which it should be covered. As a general rule, it should not be so deep as to prevent access of air and moisture, which are necessary to insure

fermentation and nitrification. In clay soils it is possible to bury the manure so deeply as to prevent decay, while in open sandy soils this danger is not so great. In very compact soils it has been recommended that the depth should not exceed 4 inches. During very dry seasons much harm may result from plowing under large amounts of coarse manure, as there may not be sufficient moisture in the soil to bring about the decay of the organic matter. This undecayed material may result in a physical injury to the soil.

Applied to sod. A practice that is highly recommended is to apply the manure as it is made to meadow or sod land that is to be plowed and planted the following spring. In this way what is applied in summer or early fall is partly used by the growing crop, thus avoiding losses, and when the sod is plowed under the entire plant food can be used by the succeeding crop. Manure applied to pasture or meadows during the summer or fall aids in conserving the moisture by its action as a mulch, as well as supplying plant food and inducing a longer season of growth.

Fresh and rotted manure. The form in which manure should be applied is determined largely by the soil on which it is to be used. On heavy soils containing large amounts of clay, more benefit will be derived from fresh manures than from those that are well rotted. The fresh manure warms these cold soils, makes them more porous, and the fermentations that take place during decay tend to make the soil more mellow.

On light or sandy soils, on the other hand, those manures that are well rotted will be found most beneficial. Such soils are likely to suffer from the drying and heating effect of raw, coarse manure, and to have their porosity increased to an undesirable extent. While it is doubtful if moderate quantities of fresh manure are seriously injurious to these soils, nevertheless, if applied in large quantities, it is much safer to have the manure well rotted. It will then improve the mechanical condition of the soil and increase its water retaining power.

Fresh manure has a forcing effect and tends to produce stems

and leaves at the expense of fruit and grain. It is therefore better for early garden truck, grasses and forage plants than for cereals or fruits. Corn is usually benefited by liberal applications of fresh manure. In fact it may be said that when in doubt as to where to apply the manure, "use it on corn." It is claimed that fresh manure is injurious to sugar beets and tobacco, producing a large beet of low sugar content and a coarse and undesirable tobacco leaf. It is a well known fact that raw manure in large quantities is likely to cause lodging with the small grains, such as barley, oats and wheat. In the case of sugar beets, experiments with fresh manure at the New York State Experiment Station have given beets of high sugar content and without rank leaf growth, results at variance with those of European experiments. Climate and soil are probably very important factors in determining what will be the comparative results with the two kinds of manure.

Instead of using the manure directly on the small grains, it is good practice, where corn is grown, to apply it liberally to that crop and plant the field to the smaller grains the following year. When this is done the danger from rank growth is minimized.

Rate of application. As to the rate at which manure should be applied, no fixed rule can be given. It will depend upon the character of the soil, the quality of the manure, the nature of the crop and the frequency of application. German authorities consider 7 to 10 tons light, and 20 tons or more heavy, applications. Sir Henry Gilbert considered 14 tons per acre, annually, excessive for wheat and barley. For ordinary farm crops it is not customary to use more than 8 to 10 tons per acre. As a general principle it may be stated that frequent light dressings pay better than very large ones at long intervals. Too liberal applications are wasteful. The amount of manure produced on the average farm is so small compared with the land to be fertilized that it would be utterly impossible to spread it over all the farm yearly. For this reason it is considered good practice to apply the manure to one crop in a rotation, thus covering only part of

the farm each year. The following three-year plan of rotation will explain the above statement; corn, 1 year; grain, 1 year; clover, 1 year; the manure is applied to the clover sod. The following table brings out clearly the relation of plant food removed by such a rotation as described above, and the quantity returned by the application of 10 or 15 tons of farm manure of average composition once in 3 years. No account is taken of losses by drainage or the gain in nitrogen to the soil of probably 50 pounds per acre, by the growth of the clover.

	Wt. crop dry per acre	Nitrogen	Phos- phoric Acid	Potash
	Lbs.	Lbs.	Lbs.	Lbs.
Corn grain 30 bushels	1500	28.0	10.0	6.5
Corn stalks	1877	15.0	8.0	29.8
Barley grain 40 bushels	1747	35.0	16.0	9.8
Barley straw	2080	14.0	4.7	25.9
Red clover 2 tons	3763	98.	24.9	83.4
Total removed		190.0	63.6	155.4
Manure 10 tons		100.0	50.0	100.0
Manure 15 tons		150.0	75.0	150.0

We see from this table that it would require once in 3 years the application of about 15 tons of manure of average composition to replace the plant food removed by the three crops.

Relation of manure to maintenance of fertility. At the Rothamsted Experiment Station, England, experiments to determine the relative value of farm yard manure and commercial fertilizers have been carried on over a very long period of time. On certain plots, crops have been grown continuously with no fertilizer, on other plots with barn yard manure at the rate of 14 tons per acre annually, and on still others, various combinations of commercial fertilizers have been tested. The tests extend over 40 years and are given in the following table as averages of five 8-year periods.

Comparative Effect of Manure and Commercial Fertilizers.

	Barley—Bushels per acre			Wheat—Bushels per acre		
	No Manure	Manure	Com- mercial Fer- tilizers	No Manure	Manure	Com- mercial Fer- tilizers
1st 8 years.....	24	44	48	16	34	36
2nd 8 years.....	18	52	51	13	35	39
3rd 8 years.....	14	49	45	12	35	36
4th 8 years.....	14	52	42	10	28	32
5th 8 years.....	11	44	41	12	39	38
Average (40 years)	16	48	45	13	34	36

It will be seen that there was practically no difference between the plots dressed with farm manure and those receiving commercial fertilizers. In fact the test was hardly fair to the manure, as excessive quantities of commercial fertilizers were applied. The amount of nitrogen added to the wheat was equal to that contained in 800 pounds of nitrate of soda, an excessive amount. It is believed by some authorities that had the experiment been conducted in America the result would have been more favorable to the barn yard manure. This judgment is based on the belief that nitrification, due to the influence of climate, would be more rapid in this country than in England.

Lasting effect of manure. Barn yard manure, because of its slow-decomposing organic matter, has a lasting effect when applied to the soil. Where, at Rothamsted, a plot was manured annually for 20 years, and then received no manure for the next 20 years, this effect is clearly shown. The following table illustrates this effect. The figures represent the action of the residual manure, as no fertilizer was added during the period covered by the table. The crop grown was barley and is expressed in bushels per acre.

Lasting Effect of Manure.

	Unmanured	Effect residual manure
First five years.....	13	39
Second five years.....	14	29
Third five years.....	14	30
Fourth five years.....	12	23
Average (20 years).....	13.2	30

The table shows that the effect of the manure was perceptible in yield for at least 20 years after the last application. In fact the value of barn yard manure cannot be estimated on the basis of the plant food it contains alone. It has a greater value than that because of its improvement on the physical conditions of the soil and the increased fermentations which result from its application. It is always a safe fertilizer for the inexperienced farmer, as there is little danger of lasting injury from its use, while it is possible to use commercial fertilizers in such a way as to make the soil poorer after their use than it was before.

Effect of style of farming on fertility. Prominent authorities in agriculture believe that in a system of strictly animal husbandry, where nothing is sold from the farm except animals or animal products, and all the manure properly saved and utilized, the fertility of the land may be maintained indefinitely without the purchase of commercial fertilizers. It should be remembered that a positive balance of plant food could not be maintained in this way unless additional feeding materials were purchased and fed on the farm. This is due to the 20 per cent loss of fertilizing materials contained in the growing animals and milk produced. While there may be large stores of potential plant food in the soil which could make up the 20 per cent yearly deficit and maintain average crop production, nevertheless, a permanent agriculture could not be founded on such practice.

In systems of animal husbandry it is the rule to purchase ad-

ditional feeding stuffs. The amount of wheat bran necessary to offset the losses on a farm from which live stock and milk are sold, is shown in the following table. The calculations are based on what a farm of 160 to 200 acres could do. Only potash and phosphoric acid are considered, as the supply of nitrogen for plant production can be maintained through the growth of leguminous crops.

Compensation of Losses on a Farm by Purchase of Wheat Bran.

		Potash	Phosphoric Acid
	Lbs.	Lbs.	Lbs.
Live stock sold.....	20,000	40	300
Milk sold.....	146,000	250	262
Total.....		290	562
Bran Purchased.....	18,000	306	630

The table brings out the fact that 9 tons of wheat bran would offset the losses sustained by the sale of farm animals and milk. Where cream is sold instead of milk, the amount of wheat bran necessary to supply the loss of potash and phosphoric acid in the stock sold would be about 5 tons.

It must be clear to the student from what has already been said, that losses in fertility are greater in any system of farming, where the crops are sold from the farm than when some form of animal husbandry is followed, especially if no commercial fertilizers are purchased. To illustrate this point more fully, the following table adapted from a Minnesota bulletin is given. Four farms, each containing 160 acres, were assumed. On the first nothing but grain was raised and sold. The second was about equally divided between grain and stock farming, and the third and fourth were devoted exclusively to stock raising and dairying, respectively. In the last two cases a small amount of the farm produce was exchanged for mill products, which accounts

for the slight gain in phosphoric acid, but it was assumed that no other concentrates or fertilizers were purchased. The decidedly smaller loss of nitrogen on the second farm and the actual increase of nitrogen on the stock and dairy farms are due to fixation of nitrogen from the growth of clover. The figures represent pounds of fertilizing material lost or gained on the farm in 1 year.

Effect of Style of Farming on Fertility.

Kind of farming	Gain or loss in fertility		
	Nitrogen	Phosphoric Acid	Potash
	Lbs.	Lbs.	Lbs.
All grain.....	-5600	-2500	-4200
Mixed.....	-1100	-1000	-1000
Stock.....	+1100	+ 50	- 60
Dairy.....	+1200	+ 75	- 85

Green manuring. The lowered crop producing power of a soil is in many instances due to the rapid decrease in the amount of humus which it contains. Humus is formed in most cases from the plants which have previously grown on the field and have later become a part of the soil. It may be produced from animal or vegetable material added as manure. Virgin soils are rich in humus, but continued cropping with no provision for maintaining the supply may result in its being decreased from one-third to one-half in a period of not more than 15 years. Humus is of importance because it is a storehouse of plant food, especially nitrogen. Most of the nitrogen of the soil is contained in the more or less decomposed organic matter present.

Plowing under green crops, grown for that purpose, is one of the oldest means of increasing the humus content of soil. By this practice, not only is the soil enriched with carbonaceous matter derived from the air, but a considerable amount of nitrates which would have been formed by nitrification during the growth

of the crop, is assimilated, converted into complex organic compounds in the plant and restored to the soil. Without the crop these nitrates would have been to a large extent lost by drainage. The planting of "catch crops" for this purpose is best done in the autumn, since nitrification is then very rapid and loss from washing out of nitrates by winter rains is to a great extent prevented.

For green manuring, two classes of crops are in common use.



Experiments showing that "green manuring" with legume plants can supply all the nitrogen needed by a succeeding crop (after Wagner).

To the first class belong such crops as buckwheat, mustard, rye, rape, etc. These kinds of plants are efficient in restoring carbonaceous matter and what nitrogen was available for their growth. They have added no essential element of plant growth. They should be plowed under before seed is produced or otherwise the land would be fouled for the next year.

To the second class belong the legumes. They have all the advantages of the first class, but in addition, increase the amount of nitrogen in the soil. Those most often recommended are red clover, the lupines, cow peas, crimson clover, soy bean and the

ordinary field bean and field pea. Red clover in the one most commonly used. They produce good results even when the crop is harvested and the stubble plowed under. At the Rothamsted Experiment Station it has been estimated that 50 pounds or more of nitrogen per acre is added to the soil annually in the roots and stubble of clover alone.

Under certain conditions green manuring may be attended by dangers. In a dry season the growth of a crop to plow under may decrease the moisture content of the soil to a point that is harmful to the succeeding crop. In such a season there may also be insufficient moisture in the soil to bring about the decomposition of the organic matter which is turned under. When green manuring is practiced in a dry season, the land should be rolled so as to establish capillarity as far as possible.

Where systems of stock farming are practiced, it appears to be a wasteful method to plow under green crops which may be suitable for feed. It would be found more profitable to feed them to the animal, carefully save the manure and return it to the fields. Green manuring will prove desirable in any system of farming where the crops are sold from the farm. On the other hand, when the farmer is engaged in stock farming and the crops are of value as feeds, then turning them under must be considered a wasteful practice.

CHAPTER VII

COMMERCIAL FERTILIZERS

It is neither possible nor necessary for all farmers to engage in stock raising or dairying in order to maintain the fertility of the land. While it is possible, as has been described, to maintain without the purchase of commercial fertilizers, a positive balance of plant food on the farm in the practice of the above systems, it is manifestly impossible to do so in a system of grain farming where the crops raised are all sold from the farm. In the latter system recourse to commercial fertilizers, supplemented by green manuring for the purpose of maintaining the humus content of the soil, must be made sooner or later.

At the present time probably \$60,000,000 are spent annually in the purchase of fertilizers in the United States, and it is no exaggeration to say that fully one-half of this is money thrown away. This is not an argument against their use, but simply means that they should be purchased with judgment and not used at all until actual investigation has shown them to be necessary.

Plant food not the only factor in crop growth. It should be remembered that other factors than plant-food supply enter into the production of large crops. Improper physical condition of the soil, lack of moisture, deficiency of humus, unsuitable soil reaction, unfavorable weather, etc., all may interfere with the normal and vigorous development of the plant and thus cause diminished crop returns, even when the plant has within reach all the food it needs. These unfavorable conditions may partly be ameliorated through means available to man, such as draining, irrigating, harrowing, liming, etc. Too frequently fertilizers are made to take the place of tillage when they should be used to supplement it. That is, fertilizers are more likely to give profitable results when used in conjunction with an excel-

lent physical condition of the soil, and the man who would obtain best results without fertilizers is the one most likely to realize a profit from their use. "The fact that fertilizers can now be easily secured, and the ease of application, have encouraged a careless use, rather than a thoughtful expenditure of an equivalent amount of money or energy in the proper preparation of the soil. Of course it does not follow that no returns are secured from plant food applied under unfavorable conditions, though full returns cannot be secured under such circumstances. Good plant food is wasted and the profit possible to be derived is largely reduced." Again, in many instances, the ease with which commercial fertilizers can be secured tends to a neglect of the home resources and one far too commonly sees the waste of farm manure and the purchase of commercial fertilizers practiced on the same farm.

What commercial fertilizers contain. Investigation and experience have shown that in most instances increased production has resulted from the addition to the soil of but three of the essential substances found in plants; namely: nitrogen, phosphoric acid and potash. It has been shown that in normal soils there are probably sufficient quantities of all the other elements which the plant requires. It was customary, soon after the time of Liebig, for agricultural investigators to add all the elements essential to plant growth, but practice soon showed that to be unnecessary, for the reason stated above. Consequently commercial fertilizers, as placed on the market today, contain only nitrogen, phosphoric acid or potash, or mixtures of these ingredients and these are the only elements giving the fertilizer commercial value.

Commercial fertilizers are made from a few basal materials which are articles of commerce. Some of these materials contain only one of the essential ingredients of a fertilizer, while others contain two, but usually one is in such excess that the material is used chiefly to furnish but the one element.

The "complete fertilizer" consists of two or more of these

basal materials mixed together to give the desired per cent of nitrogen, phosphoric acid and potash.

Nitrogenous fertilizers. This group of substances may be divided into two classes: (1) Inorganic or mineral substances;



Complete
Fertilizer

Without
Phosphoric
Acid

Without
Potash

Without
Nitrogen

Effect of fertilizer constituents upon oats grown on clay soil. Note the scarcity of foliage where no nitrogen was supplied and the low yield of grain where phosphoric acid was lacking.

(2) organic substances derived from animal or vegetable materials. The inorganic materials most commonly used are sulphate of ammonia, nitrate of soda and nitrate of potash.

Sulphate of ammonia. This material is from the gas works and is obtained as a by-product in the manufacture of illuminating gas. It is the most concentrated nitrogenous material in the market and contains from 20 to 23 per cent of nitrogen, equivalent to about 25 per cent of ammonia. It is very soluble in water, does not readily leach out of the soil, and undergoes nitrification very quickly, being converted into nitrates. However, some plants may take a part of their nitrogen supply directly as ammonium salts, when so applied. The sulphate gives good results on soils containing plenty of lime. It should not be used on soils deficient in lime, because of its tendency to leave the soil acid.

Nitrate of soda. This fertilizer is known under the name of "Chili salt petre" and occurs in deposits of considerable extent in Chili. When crude it is called "caliche" and contains varying amounts of impurities, chiefly common salt. It is freed from these impurities by solution and crystalization and when put upon the market contains from 95 to 97 per cent of nitrate of soda. This final product contains from 15 to 16 per cent of nitrogen. Chili supplies over a million tons of nitrate a year to be used as a fertilizer. This substance contains its nitrogen in the most readily assimilable form, and in the form into which most other nitrogenous bodies must be converted before they are taken up by the plant. It is not fixed by the soil and unless growing crops are at hand to take it up, it will be leached out by rains. Consequently it should be applied as a top dressing and in not too heavy applications. It is best applied early in the spring soon after the plants have started their growth and should be mixed with at least double its weight of soil before being applied, as otherwise harm to the plants may result. It should not be applied to grain crops late in the season.

Nitrate of potash. This is commonly known as "salt petre" and is one of the most concentrated fertilizing materials we have, since it contains both nitrogen and potash in available forms. It contains about 13 per cent of nitrogen and from 42 to 45 per

cent of potash. It is generally too expensive to use for manurial purposes, as it is used very extensively in various manufacturing processes.

Calcium nitrate. This product is manufactured by passing strong electric discharges through air. By this means oxides of nitrogen are produced by the union of oxygen and nitrogen. These gases are absorbed in water with the production of nitric acid. This acid is then led into milk of lime, which results in the formation of calcium nitrate. The product is next concentrated until it solidifies as a material containing about 13 per cent of nitrogen. At the present time it is almost entirely produced in Norway, where cheap water power is available, and in cheapness compares favorably with nitrate of soda. As a fertilizer and as a source of nitrogen it has given excellent results.

Calcium cyanamide is a comparatively new nitrogen-containing fertilizer and is produced by heating calcium carbide in a current of air from which the oxygen has been removed. When used as a manure it has in many cases given as good results as the same amount of nitrogen applied as nitrate of soda or ammonium sulphate. Because of its injurious effect on germinating seeds, it should be incorporated with the soil a week or so before any seed is sown. It contains about 20 per cent of nitrogen, and is to-day produced in limited quantities in this country.

Organic nitrogenous materials. In order to bring out clearly the relative value of this class of fertilizing materials they will be discussed under the following heads; first, those materials in which the nitrogen becomes readily available in a comparatively short time by decomposition in the soil; second, those materials which undergo fermentation very slowly and the nitrogen of which only becomes available after a long time. Readily available materials include such products as dried blood, meat scraps, tankage, dried fish or fish scrap, cotton-seed meal and castor pomace.

Dried blood. This material is obtained by drying the blood from slaughter houses. Two grades are found on the market.

known as red and black blood. The red variety has been more carefully dried, while the black blood has resulted from a too rapid drying. The red blood contains from 13 to 14 per cent of nitrogen, while the black variety is less constant in composition and contains from 6 to 12 per cent. Dried blood ferments very readily in the soil and is one of the most valuable organic materials.

Meat scrap or meat meal. This is a packing house product and consists of various parts of animal bodies that have been kept separate from the tankage. It is rather variable in composition, containing usually from 10 to 12 per cent of nitrogen, with a small amount of phosphoric acid—about 3 per cent. It is often used for feeding purposes, as well as for fertilizer.

Tankage. This is a general mixture of the refuse material from the slaughter houses. It has usually been steam-cooked in order to separate the fat and gelatine, a process which renders it more easily fermentable in the soil. From the great variations in the nature of the materials entering into its make-up, it must of necessity have a variable composition. It contains from 4 to 9 per cent of nitrogen and from 3 to 12 per cent of phosphoric acid. It is a valuable form of fertilizer as it supplies the crop with both nitrogen and phosphoric acid.

Dried fish and fish scrap. Most of the fish fertilizers are made from menhaden, a fish that is caught in large numbers along the Atlantic coast. The fish are steamed and pressed to extract the oil and the remaining "~~pomace~~" is dried and ground. This material contains from 8 to 11 per cent of nitrogen and 3 to 5 per cent of phosphoric acid. Some of the fish fertilizers consist of the residue of the canning factories, but these are not considered so valuable as those derived from menhaden. This material readily undergoes nitrification and is a quick acting fertilizer.

Cotton-seed meal. This is obtained by removing the hulls and oil from the cotton seed. The material is then ground and put upon the market. It contains about 7 per cent of nitrogen.

1½ per cent of phosphoric acid, and 2 per cent of potash. It is too good a food material to be used as a fertilizer, as it is considered one of the best concentrated feeds on the market. Its value as a feed is becoming more and more recognized and it is only a question of time when, like linseed meal, it will no longer be available as a fertilizer.

Castor pomace is a by-product in the manufacture of castor oil. It contains 5.5 per cent of nitrogen, about 2 per cent of phosphoric acid and 1 per cent of potash.

Slowly available materials. Under this head are classed such materials as leather meal, hoof and horn meal, and hair and wool waste.

Leather. This is a waste product from various factories and is sold as raw leather, steamed leather and roasted leather; it contains about 7 per cent of nitrogen and in the soil decays very slowly. When finely ground it is sometimes used to adulterate fertilizing material.

Hoof and horn meal is a by-product resulting from the making of various articles from hoofs and horns; it is very rich in nitrogen, carrying about 14 per cent, but decomposes very slowly in the soil.

Hair. This is another product from slaughter houses, and when dry contains from 9 to 14 per cent of nitrogen. It is very unavailable and should not be used in its natural condition for fertilizing purposes.

Wool waste is the waste product from the woolen mills and contains from 5 to 6 per cent of nitrogen and about 1 per cent of potash. It is essentially the wool fibres which have become so short by repeated spinning, weaving, etc., that they will no longer hold together. It is a low grade fertilizer.

In many states all the above resistant materials are prohibited from sale as fertilizers. This appears just, since in their original form they decay so very slowly as to make them of little value as food for plants.

Experiments indicate that if nitrate of soda is rated at 100 per cent, the availability of the other materials will be as follows:

	Per cent
Nitrate of soda.....	100
Blood and cotton-seed meal.....	70
Fish	65
Bone and tankage.....	60
Leather, hair, wool waste, etc.....	2—30

This suggests that for those crops which begin their growth early in the spring, the best results will follow the use of Chili salt-petre, as the soil is likely to be poor in nitrates and the process of nitrification slow at that time. Other crops, as corn, for example, which make their growth after the season is well advanced, can use the slower acting fertilizers; as can those crops which occupy the ground permanently.

In ordinary farming it is seldom profitable to purchase nitrogenous fertilizers, for the nitrogen of the soil can be maintained by means of farm manures and the proper use of leguminous crops in the rotation. In intensive farming, as market gardening, it will be found necessary to make liberal use of nitrogenous fertilizers.

Phosphatic fertilizers. Materials from which phosphoric acid is derived are called phosphates. Commercial sources of the phosphoric acid of fertilizers are: (1) phosphate rock; (2) bones and bone preparations; (3) basic slag; (4) guano.

Phosphoric acid is found in these materials in combination with lime, iron and alumina. In combination with lime it forms three different compounds; (1) insoluble phosphate of lime; (2) soluble phosphate of lime; (3) reverted phosphate of lime.

Insoluble phosphate of lime is known as "tri-calcium phosphate," or "bone phosphate of lime" and is composed of three parts of lime in combination with one part of phosphoric acid. It is insoluble in water and not readily available to plants. The principal materials found on the market containing this form of phosphate are:—South Carolina rock, Florida rock, Tennessee

rock, bones and tankage. They contain from 25 to 30 per cent of phosphoric acid. Ground into a fine powder, the first three are sometimes sold under the name of "floats," which on account of its fineness of division has given beneficial results, especially when mixed with stable manure or applied to soils rich in organic matter.

Soluble phosphate of lime. This substance is known under several names, as "one-lime phosphate," "acid-phosphate," "super-phosphate," "acidulated rock," etc. It is the result of treating rock phosphates or bones with sulphuric acid. By this process the sulphuric acid combines with 2 parts of the lime, forming sulphate of lime or gypsum. This leaves a compound which contains 1 part of lime and 2 parts of water, in combination with the 1 part of phosphoric acid which was contained in the tri-calcium phosphate. This substance is soluble in water, readily diffuses in the soil, and is in the most available form for direct use by the plant. A good sample of acid-phosphate contains about 16 per cent of phosphoric acid. While easily dissolved by water, it is not leached out, as several constituents of the soil such as humus, lime, iron and aluminum compounds have the power of fixing and retaining it for the use of plants.

Reverted phosphate of lime. In making super-phosphate the whole of the insoluble phosphate is not acted upon. The tri-calcium phosphate which remains after the treatment with acid, when left in contact with a comparatively large amount of soluble phosphate, causes a reversion of some of the soluble material to what is called "reverted" or "gone back" phosphate. It is also known as "di-calcium" phosphate, "citrate-soluble," and "precipitated phosphate." In composition, this material falls between the tri-calcium and mono-calcium phosphates. It is quite insoluble in pure water, but can be dissolved by weak acids, and by water containing carbonic acid, or by ammonium salts. As the soil moisture contains salts in solution, as well as carbon dioxide, this phosphate is readily assimilated by plants, and is considered an available form. This form of phosphate is considered

to be more available to the plant than the insoluble or natural phosphate; hence, the soluble and reverted phosphoric acids taken together are known as the *available phosphoric acid*.

Phosphate rock: This substance has already been mentioned under insoluble phosphate of lime. Rock phosphate is designated usually by the locality from which it is obtained, as:—South Carolina rock, Florida rock, Tennessee rock, etc. It contains 25 to 30 per cent of phosphoric acid and furnishes the chief source of the supply found on our markets. Apatite is a purer mineral



Florida rock-phosphate mining.

phosphate and it found in considerable quantities in Canada, Norway, Sweden and Spain. Mention has already been made of the finely ground rock phosphate known as "floats." Recent investigations indicate that when this material is added to farm manure it has a high fertilizing value; in fact the increased crop production at the Ohio Experiment Station, due to adding ground rock phosphate to stall manure was nearly as large as that obtained from the addition of super-phosphate. It would seem from these experiments that the comparatively inexpensive floats might, partially at least, replace super-phosphate, if used in con-

nection with manure or on soils rich in organic matter. The reason usually assigned for the necessity of incorporating this material with organic matter, is that the latter in its decay, liberates acids, which attack the phosphate and render it more available.

Bone meal or ground bone is a product of the packing houses, glue factories and soap works, the raw material being the bones of farm animals. These are either ground directly (raw bones) or after having been steamed and dried (steamed bones). This latter process removes nearly all the fat, tendons and the nitrogenous tissue adhering to the bones. The steamed bone which comes from the glue or soap factories, is, as a result of the process of steaming, poorer in nitrogen and richer in phosphoric acid than the raw bones. Raw bone contains about 2.5 per cent of nitrogen and 25 per cent of phosphoric acid, while the average figures for steamed bone are 0.5 per cent and 29 per cent of nitrogen and phosphoric acid, respectively. The effect of bone meal on crops is largely dependent on its degree of fineness, since it will be decomposed more quickly in the soil the finer it is ground. Again, the raw bone meal decomposes more slowly, due to the presence of fat which retards such processes; while the steamed bones not only allow a much more perfect pulverization, but also a more rapid decomposition in the soil, and consequently are considered of somewhat higher availability. Both materials contain the phosphoric acid in the form of insoluble phosphate of lime.

Bone ash is incinerated cattle bones, imported from South America; the nitrogenous constituents of the bones have been lost in the process of burning. It consists chiefly of the insoluble phosphate of lime and contains from 30 to 35 per cent of phosphoric acid. *Bone black* or animal charcoal is a refuse product from sugar refineries and contains about 33 per cent of phosphoric acid.

Dissolved bone is made by treating raw bone with sulphuric acid. By this process the insoluble phosphate is converted into soluble phosphate and the organic nitrogenous material into

soluble forms. This substance contains from 2 to 3 per cent of nitrogen and 15 to 17 per cent of available phosphoric acid. It will be seen that in respect to its nitrogen content it differs materially from dissolved rock or acid phosphate, which does not contain this element. The term "dissolved bone" is often used in speaking of "dissolved rock," as for example, "dissolved South Carolina bone." This use of the term is incorrect, as there is no bone in South Carolina rock phosphate.

Basic slag, also called "Thomas slag," or "odorless phosphate," is a by-product in the manufacture of iron and steel from pig iron containing phosphorus. It contains from 15 to 20 per cent of phosphoric acid in a form differing slightly from the phosphates already discussed. In this material there are five parts of lime combined with one part of phosphoric acid. The material is insoluble in water, but readily soluble in saline solutions. From the results of numerous experiments it has been found that this material has a high degree of availability, about equal to one-half that of a soluble phosphate. Its value as a fertilizer partly depends upon its fineness of division. The finer it is ground the more quickly it will become available. The fact that it contains a high lime content has made it particularly desirable for acid soils, on which it has given excellent results.

Guano. Many mixed fertilizers and fertilizing materials are incorrectly spoken of as "guano." The term should be applied to the natural product only, which consists of the excrement and remains of sea fowls, and which have accumulated in certain regions along the coast of South America and on some of the islands in the Carribean sea. There are two kinds, dependent upon the conditions under which they were formed. When the formation took place in a dry warm region, the excrement dried quickly and remained practically unchanged. This will contain all the nitrogen, phosphoric acid and potash originally in the manure. Some of the early guanos contained as high as 20 per cent of nitrogen, but those now on the market are of poorer

quality and contain from 2 to 9 per cent of nitrogen, 9 to 19 per cent of phosphoric acid and 2 to 4 per cent of potash. Where the formation has taken place in a damp climate, then fermentation occurred, resulting in a loss of nearly all of the organic nitrogen. If much rain fell, there was also a loss of nearly all of the soluble potash salts and soluble phosphates. This has produced a product containing 15 to 30 per cent of phosphoric acid in the form of insoluble phosphates of lime, iron and aluminum. This material is generally converted into a soluble phosphate by treatment with sulphuric acid, before reaching the market.

Potash fertilizers. This class of materials is generally considered of relatively less importance as fertilizers than either the nitrogenous or phosphatic fertilizers. This is true because potash compounds are usually more abundant in the soil than either nitrogen or phosphoric acid, and while most crops remove larger quantities of potash than of phosphoric acid, the former is more likely to be returned to the soil. It has already been stated that potash is most abundant in the stems and leaves of plants, and as they are the materials generally returned to the land in the form of manure, the drain from the soil of this constituent is therefore much less than in the case of the nitrogen and phosphoric acid. Of course, when the whole of the crop is removed from the soil the loss of this constituent may be very great. While these are important facts, it must not be assumed that the addition of potash fertilizers is unnecessary. It is a very necessary constituent of fertilizers, being absolutely essential for those intended for light, sandy soils, and for peaty-meadow lands, as well as for certain potash-consuming crops, as potatoes, tobacco and roots. They are also of especial value for clover, grass, corn and fruits; they should be applied in the fall on heavy clay soils and in the early spring on sandy soil. The former soils generally do not need applications of potash salts as much as sandy soils, being naturally rich in this fertilizer ingredient.

The commercial materials on the market are muriate of potash, sulphate of potash, sulphate of potash and magnesia, kainit, tobacco stems and wood ashes.

Muriate of potash is manufactured by concentration from the crude minerals obtained from the Stassfurth mines of Germany. These mines of Stassfurth are immense saline deposits, formed by evaporation of large inland seas, cut off from the ocean by geological changes. These deposits are the main source of all commercial potash fertilizers. The muriate contains about 50 per cent of potash, all of which is combined with chlorine. At the present price per ton it supplies potash at a cheaper price per pound than any of the other materials. It can be used on all soils and all crops except a few, such as tobacco, potatoes and sugar beets, which appear to be injured in quality by the chlorine present.

Sulphate of potash. This is another concentrated product of the Stassfurth industry. What is known as "high grade sulphate" contains about 50 per cent of potash in the form of sulphate. A low grade is also made, which contains from 30 to 35 per cent of potash. The sulphate of potash is of special value for those crops injured by chlorides, as mentioned above.

Sulphate of potash and magnesia. This is sometimes called "double manure salt." It is obtained from the Stassfurth mines, and contains 25 to 28 per cent of potash. It is a mixture of magnesium sulphate and potassium sulphate. Unless the cost per pound of actual potash in this material is less than in other forms, it has no special quality to recommend it.

Kainit. This is the most common product of the Stassfurth mines and is a mixture of various salts. It contains from 12 to 14 per cent of potash, chiefly in the form of sulphate. It also contains a considerable quantity of common salt, some chloride and sulphate of magnesium, a small quantity of gypsum and a small amount of potassium chloride. It is a low grade potash salt and while it is cheaper per ton, the actual potash costs more in kainit than in the muriate or high grade sulphate. For this

reason it is not desirable to purchase it for making home mixtures. As it contains chlorides it should not be used as a fertilizing material for tobacco, potatoes, or sugar beets. When used it should be carefully applied to the soil so that it will not come in contact with the seed, as it may seriously interfere with germination.

Tobacco stems. This is a by-product from tobacco factories. It readily undergoes decomposition in the soil, its potash thus be-



Potash mines at Stassfurth, Germany. Mining potash for fertilizers, coming available. It contains from 2 to 2½ per cent of nitrogen, from 6 to 8 per cent of potash and from 3 to 5 per cent of phosphoric acid. In states where it can be secured at a comparatively low price, it can be used very profitably in making fertilizer mixtures.

Wood ashes. For many years they were the sole source of potash for fertilizing purposes, but since the introduction of the German potash salts, there is less of this material found on the market. They are valuable when unleached, containing in this condition from 2 to 8 per cent of potash. They are largely

composed of carbonates of lime, magnesia and potash, with a small quantity of phosphates ($\frac{1}{2}$ per cent). The ashes from soft woods contain less potash than those from hard woods. Coal ashes have practically no value for fertilizing purposes. Wood ashes have a beneficial action on the mechanical condition of light soils, mainly because of the large amount of lime they contain. This binds the soil particles together, thus increasing their capillary action and improving their tilth. On clay soils there is a tendency for wood ashes to cause "puddling." This is avoided by applying an equal quantity of land plaster with the ashes.

All the materials mentioned with the exception of tobacco stems are soluble in water, so there is no such marked difference in availability as was noted in the case of nitrogenous and phosphatic fertilizers.

Indirect fertilizers. There are a number of substances which are beneficial to the land under some conditions, although they add neither humus nor important quantities of plant food. Among such materials are lime, gypsum and common salt.

Lime. There are very few if any soils, which do not contain sufficient lime to supply the plant. The chief value of lime applications must be as an indirect fertilizer. Its action is three-fold:—Mechanical, chemical and biological. Its mechanical effect on heavy soils is to make them less adhesive and more friable and easier to work when dry. On light porous soils its effect is exactly the reverse. It binds the particles together, increases the cohesive power and improves capillarity. Chemically, its action is important. It acts on insoluble potash compounds, liberating potash. It aids in the decomposition of organic matter. It corrects acidity by combining with the acids present. Its biological action is dependent upon the chemical reactions it induces. Its presence is a necessary condition to nitrification, a biological process. It combines with the nitric acid formed, producing nitrates. By maintaining the soil neutral, or slightly alkaline, it creates a proper medium for the growth and develop-

ment of many forms of micro-organisms, which are so necessary to the formation of available plant food.

Lime for agricultural purposes is put upon the market in several different forms:—as caustic lime; as hydrate of lime or water-slaked lime; as air slaked lime or carbonate of lime; as ground limestone rock and as ground oyster or clam shells. The caustic or quick lime is the most concentrated form and the most active. It is made up of the two elements, calcium and oxygen. When they unite we have quick lime, or calcium oxide, and this material when united with carbon dioxide forms calcium carbonate, the chief constituent of limestone and oyster and clam shells. When limestone is burned quick-lime or calcium oxide is left behind. One hundred pounds of pure calcium carbonate will yield on burning 56 pounds of calcium oxide, and 44 pounds of carbon dioxide will be driven off. From the quick lime, the slaked lime is obtained by addition of water out of contact with the air. Fifty-six pounds of caustic become 76 pounds of slaked lime. When contact of air is allowed the 56 pounds of caustic become 100 pounds of air slaked lime by again combining with the carbon dioxide of the air. Thus it will be seen that in purchasing lime it will be more economical to buy the caustic or quick lime. However, because of its quick action, care must be exercised in its use. Finely ground limestone is coming into high favor and where it can be obtained at a sufficiently low cost is undoubtedly the safest form to use, especially by the inexperienced. Lime should be applied to the surface and if possible thoroughly incorporate with the few upper inches of the soil. The clovers and other leguminous plants require more lime than do the cereals and are much more sensitive to acidity of the soil. A good stand of clover, therefore, is an indication that the soil contains sufficient lime.

Gypsum or land plaster is a sulphate of lime and has given excellent results with clover and other leguminous plants. It is now generally believed that its beneficial action is due to the fact that the plaster sets free the unavailable potash of the soil.

It is of value to those crops that are benefited by the use of potash. For that reason it gives best returns when used on soils rich in potential potash, as the clays, with practically no beneficial results when applied to sandy soils. Its use as a source of sulphur must not be overlooked, as it is possible that the beneficial results obtained in many cases by its application will have to be traced back to the additional supply of this element.

Salt has sometimes been used as a manure. It is certain that in special cases it has given beneficial results, but in other instances injury has resulted. It is well known that salt checks fermentations of all kinds so that it probably influences the rate of nitrification going on in the soil. It is said that adding salt will make the straw of wheat stiffer, but this effect is probably due to the fact that salt depresses the plant's growth, making the straw shorter and consequently stiffer, due to reduced length.

Mixed fertilizers. The tendency of the fertilizer trade in this country has been toward the manufacture and sale of mixed fertilizers. They have been sold in the form known as *complete* fertilizers, which consist of a mixture of two or more of the basal materials heretofore described. Where the basal material alone is richer in the essential ingredient than is desired by the manufacturer, sufficient gypsum, dry earth, peat or other inert matter is added to bring the percentage of these ingredients down to the desired point. Mixed fertilizers are indiscriminately recommended for general use and all sorts of startling claims are made for them by the manufacturers. They are offered as universal fertilizers, irrespective of the well known fact that soils differ widely in their characteristics and that the crops vary in their food requirements. So-called *special* fertilizers, designed for special crops and supposed to be adapted to their particular needs, are common on the market. Some manufacturers offer a *corn special*, a *potato special*, a *tobacco special*, etc. Unfortunately their chief claim lies in their attractive names. The science of plant nutrition has not advanced to that stage where one can define what the minimum of essential elements necessary

for the maximum growth of the plant should be. And even if we had such information, the makers of fertilizer mixtures entirely disregard the quantities of plant food already existing in the soil to be treated. When the farmer studies the apparent needs of his fields and understands the subject of fertilization of crops, he will prefer to buy the basal fertilizing materials of definite, known composition and make the proportion best adapted to his needs, rather than buy mixed fertilizers.

High and low grade fertilizers. As the basal materials used in compounding fertilizing mixtures differ greatly in the amounts of plant food they contain, it will be seen that products made by mixing these materials will contain very different percentages of nitrogen, phosphoric acid and potash. If, for example, dried blood, bone meal and muriate of potash were used, the fertilizer would have a high content of plant food, while if low grade tankage, wood ashes, or kainit were employed, the product would have a low percentage. The first example illustrates a high grade product, while the second would be considered as low grade.

As the low grade material can be sold at a comparatively low price, these materials find a ready market, although the plant food in the cheap fertilizer actually costs more per pound. This fact is clearly brought out in the following table taken from a recent bulletin of the New York Experiment Station. (Geneva).

Average Cost of One Pound of Plant Food to Consumers.

	Nitrogen	Phosphoric Acid	Potash
	Cts.	Cts.	Cts.
Low grade complete fertilizer	26.3	8.0	6.8
Medium grade complete fertilizer	23.2	7.0	6.0
High grade complete fertilizer	19.6	6.0	5.0
Dried blood	18.5	.....	.....
Nitrate of soda	13.9	.....	.....
Acid phosphate .....	.....	5.1	.....
Muriate of potash .....	.....	.....	4.6

It will be seen that the price per pound of plant food is very much less in high grade goods than in low grade goods, and further, that the essential elements can be purchased separately more cheaply than in any mixed fertilizer.

Home mixing. The above facts emphasize the wisdom of the purchase of basal materials and home mixing. The difference in cost of complete fertilizers and the basal materials per pound of plant food is to be partly attributed to the expense of bagging and mixing. This, Voorhees has shown to amount to about \$8.50 per ton. That this practice of home mixing is entirely satisfactory has been abundantly proven by the Eastern Experiment Stations. It allows the uniting of the different elements in the proportions which have been found to meet best the requirements of the crop and the soil on which the crop is to be raised. By buying the basal materials separately it is possible to apply the different elements at different times. This point may be of great advantage in feeding a crop, especially one needing large quantities of nitrogen.

The conditions and materials necessary to do the mixing are a good, tight barn-floor, or a dry, smooth earth-floor, platform scales, rake, hoe, shovel and screen.

Selection of commercial fertilizers. It is impossible to give definite directions as to the kinds and quantities of fertilizers required for different crops, because soils differ greatly in their total content of plant food, and we have no direct and safe method by which the amounts of *available* plant food can be accurately determined. By noting carefully the growing crops, we may get in a general way, some valuable suggestions as to which of the constituents is probably lacking in a soil. For instance, when the crop has a deep green color, with well-developed leaf and stalk and luxuriant growth, it may be assumed that the soil is not deficient in nitrogen and potash. A rank and excessive growth of leaf and stem, with imperfect bud and flower development indicate excessive nitrogen for the potash and phosphoric

acid present. When grain crops tend to mature early, with well defined, well developed, plump and heavy kernels, there will be little doubt that the soil contains a good supply of available phosphoric acid. Potash fertilizers are, generally speaking, of special benefit in the case of leafy plants like tobacco, cabbage, beets, clover and potatoes. While some help may be had from the above suggestions, nevertheless definite methods of procedure have been proposed by several investigators, and will be discussed briefly.

Ville system. "The system which has perhaps received the most attention, doubtless largely because one of the first presented, and in a very attractive manner, is the one advocated by the celebrated French scientist, George Ville. This system, while not to be depended upon absolutely, suggests lines of practice which, under proper restrictions, may be of very great service. In brief, this method assumes that plants may be, so far as their fertilization is concerned, divided into three distinct groups. One group is specifically benefited by nitrogenous fertilization, the second by phosphatic, and the third by potassic. That is, in each class or group, one element more than any other rules or dominates the growth of that group, and hence each particular element should be applied in excess to the class of plants for which it is a dominant ingredient. In this system it is asserted that nitrogen is the dominant ingredient for wheat, rye, oats, barley, meadow grass and beet crops. Phosphoric acid is the dominant fertilizer ingredient for turnips, Swedes, Indian corn, (maize), sorghum, and sugar cane; and potash is the dominant or ruling element for peas, beans, clover, vetches, flax, and potatoes. It must not be understood that this system advocates only single elements, for the others are quite as important up to a certain point, beyond which they do not exercise a controlling influence in the manures for the crops of the three classes. This special or dominating element is used in greater proportion than the others, and if soils are in a high state of cultivation, or have

been manured with natural products, as stable manure, they may be used singly to force a maximum growth of the crop. Thus, a specific fertilization is arranged for the various rotations, the crop receiving that which is the most useful. There is no doubt that there is a good scientific basis for this system, and that it will work well, particularly where there is a reasonable abundance of all the plant food constituents, and where the mechanical and physical qualities of the soil are good, though its best use is in 'intensive' systems of practice. It cannot be depended upon to give good results where the land is naturally poor, or run down, and where the physical character also needs improvement."

Wagner system. "Another system which has been urged, notably by the German scientist, Wagner, is based upon the fact that the mineral constituents, phosphoric acid and potash, form fixed compounds in the soil and are, therefore, not likely to be leached out, provided the land is continuously cropped. They remain in the soil until used by growing plants, while the nitrogen, on the other hand, since it forms no fixed compounds and is perfectly soluble when in a form useful to plants, is liable to loss from leaching. Furthermore, the mineral elements are relatively cheap, while the nitrogen is relatively expensive, and the economical use of this expensive element, nitrogen, is dependent to a large degree upon the abundance of the mineral elements in the soil. It is, therefore, advocated that for all crops and for all soils that are in a good state of cultivation, a reasonable excess of phosphoric acid and potash shall be applied, sufficient to more than satisfy the maximum needs of any crop, and that the nitrogen be applied in active forms, as nitrate or ammonia, and in such quantities and at such times as will insure the minimum loss of the element and the maximum development of the plant. The supply of the mineral elements may be drawn from the cheaper materials, as ground bone, tankage, ground phosphates and iron phosphates, as their tendency is to improve in character; potash

may come from the crude salts. Nitrogen should be applied as nitrate of soda, because in this form it is immediately useful, and thus may be applied in fractional amounts, and at such times as to best meet the needs of the plant at its different stages of growth, with a reasonable certainty of a maximum use by the plant. Thus no unknown conditions of availability are involved, and when the nitrogen is so applied, the danger of loss by leaching, which would exist if it were all applied at one time, is obviated."—(Voorhees.)

System based on the analysis of the plant. "Still another system is based on the food requirements of the plant as shown by the analysis of the plant itself. The amount of plant food removed from each acre of ground is calculated from the analysis of the plant and a corresponding amount is returned to the soil. Different formulas are, therefore, recommended for each crop, and in these the nitrogen, phosphoric acid and potash are combined in the same proportions in which they are found in the plant. Experience shows that it is necessary to add amounts of these fertilizers to the soil that will supply more plant food than is removed by the crop if the maximum results are desired. This system may result in a large yield, but cannot be considered an economical method of feeding the plant, as one or more of the elements is likely to be applied in excess of the requirements of the crop. It does not take into consideration, for instance, the fact that a plant which contains a large amount of one element of plant food may possess unusually great power of procuring that element from the soil. The principle underlying this system, of course, is the idea that to maintain the fertility of the soil unimpaired an amount of plant food equivalent to that removed by the crop must be returned to the land. To this extent the system is similar to the use of barnyard manure, but is not so effective."

Money crop system. "Another system used in ordinary or extensive farming is to apply all the fertilizer to the money crop

of the rotation. This method is used especially where only one crop in a rotation is sold, the others being fed on the farm. A liberal supply of food is used to give the maximum yield which the climate and season will permit. The amount of food applied is in excess of the requirements of the crop and the residue is depended upon to help nourish the succeeding crops, or at least the one immediately succeeding the money crop. This system has some valuable features and is probably the one most in use in this country at the present time.

"Too frequently fertilizers are used by what certain writers have called the 'hit or miss' system. No special thought is given to the requirements of the crop or the composition of the fertilizer, but if a farmer feels that he can afford it and the agent is a glib talker, the sale is made. If the buyer happens to 'hit' the food requirements of his crop a profit is secured and he is correspondingly happy, while if he makes a 'miss' he feels assured that there is no value in commercial fertilizers."—Vivian.)

Field experiments necessary. These systems described have their good features, but they do not take into account the important fact that soils differ greatly in the amount and availability of the plant food they already contain. In order to determine with any degree of certainty what particular constituents are needed the farmer must conduct some experiments for himself. This can be done by carefully marking off certain portions of the field, of definite size and uniform soil, and using on them different fertilizing materials. Plots one rod wide and 8 rods long, and containing $1/20$ of an acre, are of convenient size. The diagram on page 170, taken from Vivian, shows the arrangement and kinds and quantity of materials to be used on each plot.

Careful notes should be made during the growing period and at the end of the growing season and when the crop is harvested comparison made as to the yields by weight obtained. In this way definite information will be secured as to whether the soil

is lacking in one or two, or all three of the constituents of plant food in available form. In carrying out field tests such as these it should be borne in mind that the results of one year's work are not perfectly reliable, since prevailing weather conditions, as well as other factors, may produce very different results. It will be well to continue the work for several years in order to eliminate any differences due to differences of season.

No Fertilizer
15 lbs. Nitrate of Soda 15 lbs. Sulphate of Potash 30 lbs. Acid Phosphate
30 lbs. Acid Phosphate 15 lbs. Sulphate of Potash
No Fertilizer
15 lbs. Nitrate of Soda 15 lbs. Sulphate of Potash
15 lbs. Nitrate of Soda 30 lbs. Acid Phosphate
No Fertilizer

It must also be remembered that the requirements for different crops will vary. By carrying the plots through several seasons and using the rotation common for that particular farm, the special crop needs can also be ascertained.

Amount of fertilizers to be applied. No definite rules can be given as to the quantities of commercial fertilizers to be applied, for the amount necessary to produce large crops will vary with the character and state of fertility of the soil, the kind of crop

to be grown, the time and manner of application and many other factors. Five hundred pounds per acre may be considered a heavy application for ordinary farm crops; applications of more than that amount will only give economical returns in the case of special crops grown under an intensive system of farming. Heavy applications at long intervals are not as productive of good results as light applications more frequently. It is better not to make applications of over 200 pounds per acre of any one basal material and to vary the amount from year to year until experience has shown that economical returns can be expected by heavier applications. Lime may be applied at the rate of 1000 pounds per acre on light soils and double that amount on heavy soils. This application once in 5 or 6 years is usually sufficient.

Fertilizer laws and guarantees. To protect the farmer against the sale of fraudulent and spurious goods, the manufacturers are compelled by law in most states, to give the actual amounts of the different constituents contained in their products. Usually they are compelled by law to state on each bag or parcel offered for sale the percentage of nitrogen (or ammonia), available phosphoric acid and potash. The enforcement of the law and the chemical examination of the fertilizers to determine if they agree with the guarantee, rests with the State Experiment Station, or in some states with the State Department of Agriculture. The results secured are published in bulletins available to the farmers of the state, and should be consulted freely by those buying such materials. These laws have resulted in almost complete disappearance of materials compounded with the intention of defrauding, as well as a great lessening in the number of brands offered for sale. Nevertheless, statements often appear on the bags, which, to say the least, are confusing and may mislead the buyer. Phosphoric acid, 10 per cent, for example, is often stated as equivalent to bone phosphate, 22 per cent. To the buyer the higher figure is attractive and he is led to believe that he will obtain something more than the 10 per cent of phos-

phoric acid guaranteed. The following example, taken from the label of a fertilizer bag, will explain this point more fully:—

GENERAL CROP BRAND.

Guaranteed Analysis.

Nitrogen	0.82— 1.65 per cent	
Ammonia	1.0 — 2.0	"
Available Phosphoric Acid.....	8.0 —10.0	"
Equal Bone Phosphate.....	17.0 —21.0	"
Total Phosphoric Acid.....	10.0 —12.0	"
Potash Sulphate.....	11.0 —13.0	"
Potash	6.0 — 7.0	"

Color not guaranteed.

The buyer is only concerned in the total amount of nitrogen, available phosphoric acid and potash that the brand contains. and these figures alone should dictate the actual worth of the material.

CHAPTER VIII

CROPS.

Having considered somewhat in detail the chemical composition of plants and the functions of the chemical elements concerned in their growth, we are in a position to discuss in general terms the relative composition and food requirements of crops, and the factors influencing their composition and feeding value. For the sake of convenience, the common crops will be considered under the following arbitrary divisions:—

- I. *Seed crops*—including,
 - a. Cereal grains, such as wheat, corn, rye, barley, oats and rice.
 - b. Leguminous seeds, such as beans, peas, cowpeas and soy beans.
 - c. Miscellaneous seeds, such as cotton seed, flaxseed, castor beans and others.
- II. *Hay or fodder crops*—including,
 - a. Common grasses, such as timothy, red top and Kentucky blue grass.
 - b. Cereal plants, such as corn, oats, barley and other crops, cut at an immature stage for soiling purposes, silage, or hay.
 - c. Leguminous crops, such as alfalfa and the various clovers (which form true hays), and the pea, cow pea, vetch and soy bean (when cut green for soiling purposes or for curing as hays).
- III. *Root crops*—including,
 - a. True roots, such as mangels, turnips, beets and carrots.
 - b. Tubers, or subterranean stems, such as potatoes.
- IV. *Fruit crops*—including,
 - a. Fruit of perennial plants, such as the apple, pear, plum, peach, grape and most berries, as well as the orange, lemon, banana and other tropical fruits.

b. Fruit of annual plants—such as melons, pumpkin, squash and tomato.

V. *Forest growth*—including, hardwooded and softwooded perennial plants.

VI. *Miscellaneous crops*—including, tobacco, and the onion, cabbage, and other truck crops.

In considering the seed crops we must take into account the straw as well as the grain. The former portion of these crops is not important in all cases as a feeding material, but it always stands responsible for a part of the exhaustion of plant food from the soil. For this reason the tops as well as the roots of root-crops should be considered.

The yield of crops, both in the total substance produced and in its proportion of plant compounds, varies widely. These factors control to a large extent the value of the crops as feeding-stuffs, and their demands upon the plant food constituents of the soil. A rational comparison of the composition of crops can be made only upon the basis of yield of dry matter and of the individual nutrient compounds or groups of compounds contained therein, per acre. The following table gives the total

Yield in Pounds Per Acre.

	Fresh material	Dry matter	Crude protein	N. free extract	Ether extract	Crude fiber	Ash
Alfalfa.....	35,000	9,870	1,680	4,305	350	2,590	945
Corn	30,000	6,270	510	3,300	240	1,800	420
Red clover.....	18,000	5,256	792	2,430	198	1,458	378
Timothy.....	11,500	4,416	356	2,323	138	1,357	231
Hungarian grass...	19,000	3,591	589	2,698	133	1,748	323
Mangels.....	60,000	5,400	840	3,300	120	540	660
Sugar beets.....	32,000	4,320	570	3,136	32	288	288
Potatoes.....	18,000	3,798	378	3,114	18	104	180
Oats.....	1,120	995	132	668	56	106	33
Oat straw.....	4,000	3,672	160	1,696	92	1,480	204
Barley.....	1,200	1,069	147	837	21	32	28
Barley straw.....	4,000	3,432	140	1,560	60	1,400	228
Cabbage.....	18,460	4,800	1,200	1,900	200	750	700
Tobacco (leaf)....	12,340	1,730	300	935	51	263	321

yields and the yields of proximate constituents of such comparable amounts of crops.

The differences between weights of fresh material and of dry matter in the above table are due almost entirely to water lost in the process of complete curing or drying. For example, corn in the green state consists of nearly 80 per cent of water, potatoes have about the same amount, sugar beets contain about 86 per cent, and mangels consist of over 90 per cent of this constituent. The several hay crops of the preceding table are rather lower in water, containing from 60 to a little over 70 per cent. This amount is greatly reduced by the curing process so that the hays contain only from 10 to 20 per cent.

The field cured grain crops carry from 7 to 9 per cent of moisture in the straw and about 11 per cent in the seed. The high water content of some of these crops, aside from its detrimental effect upon keeping qualities, is sometimes of importance with reference to economy of transportation. For example, since the root crops retain most of their original water content during proper storage, it is evident that a given amount of dry food material is handled far less economically in them than in grains and hays. It will be observed that the enormous acre-yields of these crops, particularly of the mangel, are reduced to moderate figures when considered in terms of dry matter.

The high protein content of the legume hays (clover and alfalfa) is in marked contrast to the amount of this group of constituents in the common hays and the cereal crops. This difference will be discussed in detail in the consideration of individual crops. Mangels also contain a high percentage of "crude protein;" but it has been shown that more than one-half of the nitrogen upon which this figure is based is not in the form of protein but is contained in amide compounds. This is probably true for other root crops, and greatly diminishes their apparent protein value.

With reference to the production of fat, it should be stated that while the grains may yield quite pure fats to the chemist's

method of analysis, this will be far from true in the case of hays and straws. Considerable amounts of chlorophyll will contaminate the "crude fats" determined for the hay crops. The high yield of ether extract in alfalfa hay, as in the case of other constituents of this crop, is incident to a large total yield of dry matter obtained from the several successive cuttings per season. In this respect, this crop possesses a marked advantage in comparison with the others.

A large proportion of the ash of cereal straws, some of the cereal grains, and the common hays, consists of non-essential silica. The legumes and root-crops in general, however, are very low in this constituent. The excessive ash content of alfalfa, the mangel, the cabbage and other crops is notable; being composed chiefly of such essential constituents as lime, potash, and phosphoric acid, it has a significant bearing upon the well-known exhaustive effects of these crops upon the soil. (A knowledge of the amount and composition of the ash of crops gives a basis for the selection of animal rations, well-balanced in ash constituents.)

The relative drain of some crops upon the soil is shown by the table in the appendix quoted from Warington. The figures for sulphur trioxide have been corrected in most cases on the basis of determinations made at the Wisconsin Experiment Station. The older determinations of sulphur by analysis of the ash have been shown to be low. Other data have been compiled from various sources and added to Warington's table.

The food requirements of cereal grains, as shown by a general survey of the table, are not widely variant. It will be observed that the ash constituents are uniformly much higher in the straw than in the grain. Nitrogen, on the other hand, accumulates chiefly in the grain, about two-thirds of the total nitrogen removed being found in this part of the crop. The separate constituents of the ash show great differences in their relative distribution between grain and straw. Thus, while potash, soda, lime, chlorine and silica are located chiefly in the straw, the greater part of the phosphoric acid occurs without exception in

the grain; sulphur trioxide and magnesia are quite evenly divided between the two parts of the crop.

Nitrogen and phosphoric acid are probably the plant food constituents most frequently lacking in soils and in many cases their depletion is to be attributed to continuous raising and selling of grain crops. It is evident that either the manure from grains fed on the farm should be carefully husbanded, or equivalent returns of plant food to the farm should be made by the purchase of feeding stuffs or fertilizers. This subject has been fully discussed in the chapter on Manures. It applies with particular emphasis to cereal crops, because they are wholly dependent upon stores of available nitrogen in the soil for their supply of this element and generally thrive best when supplied with available forms of phosphoric acid.

The conservation of the smaller amounts of plant food in cereal straws likewise should not be neglected. The practice of disposing of these straws by burning is a wasteful one, for by this treatment the nitrogen which they contain is entirely lost.

Food requirements of the common grasses. The common hays, represented in our table by meadow hay, are essentially straw crops, and their food requirements practically duplicate those of the cereal crops. Hays of the legumes show marked differences from the true hays. While for example, clover hay removes twice as much nitrogen from the land as do the cereal crops or meadow hay, it should be borne in mind that, like other legumes, this crop obtains almost all its nitrogen from the air through the activity of bacteria living in association with its roots. As will be demonstrated further on, these crops increase rather than diminish the supply of nitrogen in the soil.

The true legume hays develop extensive root systems and draw heavily upon the ash constituents of the soil. This applies in a limited degree to phosphoric acid, but more particularly to potash and lime, which form one-half the total ash of the bean crop, two-thirds of the ash of clover hay, and nearly as large a proportion in the case of alfalfa hay. The legume family of plants is es-

pecially sensitive to acid conditions of the soil. This is probably because such a medium is unfavorable for the activity of nitrogen-fixing bacteria. This condition cannot develop in a soil properly stocked with lime.

The leguminous grain crops such as beans or peas are less exhausting to the minerals of the soil than are the hays of legumes, for they develop a less extensive root system. These crops show the same general distribution of constituents between the grain and straw as do the cereal crops, and, as with the latter crops, the greater part of the nitrogen and phosphoric acid is removed in the seed.

Requirements of root crops. The true root crops are pre-eminently soil-exhausting crops. Not only do they assimilate greater amounts of ash constituents per acre than the other crops removed from the soil, with the exception of alfalfa, but they remove more nitrogen than the cereals or grasses. In the case of turnips, this amount of nitrogen is seen to be twice that removed by cereal grains or meadow hay, and in the case of mangels, it is three times as much as these crops contain. It is important to realize that the root crops are entirely dependent upon the soil for this important element of plant food. Potash is uniformly conspicuous for its high proportion in the ash of these crops. Its presence is explained by the fact already observed, that this mineral is essential to the production of starch and sugar, which are predominant compounds in these crops. Since the amounts of phosphoric acid removed by these crops are also uniformly high, it is apparent, as demonstrated also by practice, that they require especially complete and heavy manuring when grown under intensive cultivation.

Requirements of fruit crops. This class of crops is less exhaustive and less dependent upon immediate manuring than the crops already discussed; the individual requirements will be considered later.

Requirements of forest growth. Timber growth exceeds most of the other crops discussed in the annual production of dry mat-

ter, but this increase is obtained at small expense in plant food. According to Warrington, the production of 3000 pounds of dry pine timber requires the consumption of only $2\frac{1}{2}$ pounds of potash and 1 pound of phosphoric acid per acre yearly. Harder



Note the difference in the extent of the root system of the two plants, alfalfa and barley.

woods require rather more of these constituents. The amount of **nitrogen** in wood is very small, amounting to an average of about 10 pounds for an annual growth of beech wood. Trees produce seed only at mature age and then at the expense of material stored in the leaves and wood.

The litter which accumulates during the earlier years of growth will therefore be most effective in increasing the value of the surface soil by stores of plant food obtained from the deeper soil layers. As a result of this process, the manurial requirements of the forest are low and become much smaller than in ordinary cropping.

Requirements of truck crops. The various truck crops differ widely in productiveness and feeding habits. Of the more important ones, the cabbage assimilates large amounts of ash constituents, with the exception of silica. The heavy yield desired with such crops entails a correspondingly high consumption of nitrogen and necessitates heavy manuring with this element, as well as liberal manuring with potash and phosphoric acid. The high content of sulphur tri-oxide in this crop and in the turnip and other members of the cruciferae, suggests that in some cases this element may become the limiting factor in plant growth, and that the beneficial effects sometimes observed from the application of gypsum may be due to the sulphur tri-oxide which it supplies.

The tobacco crop is a comparatively light feeder, but makes positive demands for nitrogen, potash and lime.

Crop residues, which include the leaves of root crops, the straws of grain crops, the stalks of tobacco and waste parts from trimming, contain sufficient plant food to justify the exercise of care to return them to the soil. Potash and lime are the constituents of most concern in the straws and they are of even greater consequence in the leaves of root crops. The common practice of spreading tobacco stalks to decay upon the land, makes possible, as indicated by the table, the returning of considerable amounts of potash and also of nitrogen to the soil. These crop residues are frequently reduced to ashes to economize labor in their disposal, but this practice should be discouraged, since it involves a loss of much nitrogen.

Whenever the soil will profit by the addition of organic matter, these materials should be turned in whole. Another prac-

tice, much better than burning, is to compost such material with soil. In this way, both nitrogen and the ash constituents are conserved as the organic matter decays.

Individual characteristics of crops may be taken up now more in detail.

Wheat. This important grain represented 25 per cent of the value of cereal crops and 13 per cent of all crops in 1900. Sixty-two per cent of the cereal products milled in that year were from wheat. Over one-third of the farms in the United States raised wheat, with a total production in 1900 of 35 billion bushels. Extensive breeding of this grain has led to the production of about 245 leading varieties.

The crop is commonly sown in the fall and grown as "winter wheat." As a result, it has a longer period of growth and a more extensive root system than most of the cereals. The roots, which are especially developed in Durum wheat, have been found to reach a length of four, and even of six feet. These conditions enable the plant to feed effectively upon the soil. The necessary omission of spring tillage in the case of this crop, prevents the aid of this important stimulus to nitrification and renders wheat dependent largely upon manurial supplies of available nitrogen. Its extensive root system and long period of growth aid this plant in deriving its mineral constituents from the soil and make it more independent of available potash or phosphate fertilization; nitrates or ammonium salts consequently are recommended as the chief fertilizer treatment.

The wheat kernel, according to Bessey, is separated mechanically into the following proportion of parts:—

Coatings (or bran layers).....	5	per cent
Gluten layer.....	3—4	"
Starch cells.....	84—86	"
Germ.....	6	"

Protein and fat are highest in the germ and bran, ash is highest in the bran, and the fibre is confined almost exclusively to this coating. Starch is the characteristic, and by far the most

abundant constituent in wheat, as it is in all the cereal grains. This constituent is highest in the flour, which represents the interior of the kernel. (The composition of grains and other crops and of their more important products will be found in tables in the Appendix.)

It is a significant fact that about 80 per cent of the phosphoric acid of this grain is located in the bran. This makes possible the return of much of this important constituent to the farm in wheat bran and its eventual recovery in the manure. The gluten or gum-forming portion of the wheat grain is composed of two proteins, glutenin and gliadin, which form about 85 per cent of the total proteins of the seed. The tenacity of bread dough and of macaroni made from wheat flour, is due to gliadin. Considerable attention has been given to the factors affecting the amount and composition of gluten in wheat and to the consequent milling qualities of the grain and baking qualities of the flour. According to Snyder, the most valuable wheats for bread making purposes are those in which 80 to 85 per cent of the protein is gluten and the gluten is composed of from 60 to 65 per cent of gliadin and 35 to 40 per cent glutenin.

Wheat straw has little value to the stock feeder except as litter. Experiments have shown that when consumed it leaves little surplus of food value to the animal above the energy required for mastication and digestion. But when the straw is pulped by the process commonly used in paper making, the residual tissue has been shown to have a food value equal to that of starch. The plant food in the straw should be saved by utilizing it as litter or composting in the manner already described.

Rye, like wheat, is sown chiefly in the fall. It closely resembles the latter in its composition and habits of growth. The growth of this crop in early spring may be stimulated by adding 100 to 150 pounds of nitrate of soda per acre.

Rye grain is slightly lower in fat and protein than is wheat. Its gluten is not so well suited for bread making as that of wheat, but rye flour produces a coarse bread which is consumed to a

considerable extent. The straw of this crop is high in fibre and the nutrient compounds which it contains are less digestible than those of oat or barley straws, so that it possesses little feeding value.

Barley has been developed into many varieties, which fall mostly into either the two rowed or the six rowed type. It may be sown in the fall and wintered, but it is more distinctly a spring crop than is rye or wheat. It is hardier than the latter, being adapted to wider ranges of latitude and climate. The crop grows rapidly and is more exhaustive of surface soil minerals than the cereals already discussed, because of the limited feeding area of its root system. This limitation, together with its comparatively short period of growth, makes the crop more dependent upon liberal manuring than are wheat or rye. Spring tillage, however, aids nitrification and reduces the requirement for available nitrogenous manures. Its comparatively limited root system and short time of growth makes it especially responsive to soluble phosphate manuring. Excessive supplying of nitrogen to this crop is to be avoided, not only because of the coarse rank growth which it induces at the expense of seed production, but also, because the high protein content of the grain, consequent upon such manuring, unfits it for malting purposes.

Barley is richer than wheat in ash, fibre and protein; the former two constituents are largely contributed by the hull of this grain. It is slightly poorer in fat and carbohydrates than is wheat. Barley gluten does not possess the property required for bread making, and consequently the grain finds only a limited use for human food. It is fed to horses and cattle and is highly esteemed for the production of pork.

The production of malt from barley gives this grain its chief value. To produce this, the grain is soaked in water for some time and spread upon floors in thick layers. Germination ensues and heat is evolved in the process. When the sprouts are about one-half inch long, the grain is heated sufficiently in an

oven to kill the embryo. The sprouts are then removed, dried and ground, and put upon the market as a feeding-stuff under the name of "malt sprouts." The remaining grain, known as "malt," does not differ much in composition from the original barley; but the germinating process has produced and activated an enzyme of the seed, known as "diastase." If the malt is heated now with water for some time at 120° F., a process known as "mashing," this enzyme converts the starch of the grain into soluble carbohydrates. Diastase has been found capable of thus transforming 2000 times its own weight of starch into dextrines or maltose. Since the amount of this enzyme in barley is capable of transforming much more starch than is associated with it, unmalted barley or other starchy grains, such as corn, are frequently added to the mash. The maltose produced in this manner, together with other substances, is dissolved in the liquor of the mash and may be drawn off and seeded with the proper yeast to undergo alcoholic fermentation. This fermentation results in the production of beer and other liquors.

The residual grain, which contains the fat and protein originally present, is placed upon the feeding stuff market as "wet or dried brewers' grains." The latter form is preferred for its more economical handling and better keeping qualities.

Barley straw, when used in feeding experiments, has been shown to be more completely digested by ruminants than is the straw of wheat or rye, thus giving it a limited value for feeding purposes. This fact has also been demonstrated by practice.

Oats is also a crop which spring sowing and tillage aids. The spring tillage, in preparing the land for sowing, acts as an aid to nitrification and makes it unnecessary to apply the directly available nitrogenous fertilizers. But its short growing season renders it dependent upon liberal manuring to produce maximum yields. Excess of nitrogenous manure should be avoided because of the disastrous results from over-development of the foliage of the crop. Much of the "lodging" of oat crops on

heavy soils is probably due to excessive production of nitrates from humus or manure, which induces a rank growth of weak-stemmed plants.

Oat grain consists of approximately 70 per cent kernel and 30 per cent hull. The large proportion of hulls accounts for the high fiber and ash content of the grain and reduces its digestibility. On the other hand it appears to be of value for its mechanical, laxative effect upon the digestive tract. This grain is notable among the cereals on account of its high content of fat. The ground, hulled kernels, known as "oatmeal," is much used for "breakfast foods." The residual grain and poorer kernels are worked into oat feeds. Whole oats is much prized by the horse feeder. It has been supposed that the grain possesses peculiar tonic properties, due to a specific compound, but there are no scientific data in support of this view.

Oat straw is more palatable than the other cereal straws and possesses some value as a food for cattle and sheep.

Corn, or maize, has formed over 50 per cent of the acreage of cereals in the United States for several decades. In 1900 it formed 56 per cent of the value of cereals and 28.5 per cent of the value of all crops. The white man discovered it under cultivation by the American Indian and gave to it the name Indian corn. Continuous breeding has developed many improved varieties, which differ widely in size, form, color and chemical composition. The common varieties of corn fall under three subspecies: dent, flint and sweet corn. By far the greatest number of varieties are of the dent species. This species derives its name from the characteristic indentation of its crown, due to shrinkage of the starch cap as the grain dries. Flint corn is characterized by a smooth, firm coat, supported by a layer of hard or horny starch, so that the grain retains its shape as it dries. Sweet corn is characterized by a high percentage of sucrose and develops a prominently wrinkled surface, as a result of shrinkage in drying.

Examination of a longitudinal section of a corn grain made by splitting it across the thin dimension, shows it to consist of

four prominent parts, as follows:—germ, light colored starch cells, dark gluten layers and a thin outer coating. The germ is located at the tip of the kernel and is more or less completely surrounded by starch, which forms the floury portion of the grain. Outside the starch, nearly or completely surrounding it and more or less blending with it, is the yellowish gluten layer. The whole kernel is covered by a thin coating which forms a small amount of bran in the milling process. The germ contains most of the fat of the corn grain, while the gluten is the portion richest in protein. That portion of the starch bordering upon the gluten layer differs in character from the common, floury starch, and is known as “horny” or “glossy” starch. Almost all of the starch of popcorn is of this variety.

Corn is slightly lower in protein and much higher in fat than is wheat. The latter constituent is sometimes separated from the grain on a commercial scale as corn-oil. Corn meal is low in fiber and pentosans, the carbohydrates being nearly limited to starch. As a result, corn is used extensively in the production of sugar by the process already described under “glucose,” the commercial product being known as “corn syrup.” The residue from this process is sold for stock feeding as “gluten feed.” To a limited extent, it is also separated into such fancy feeds as “corn bran,” “gluten meal” and “germ oil meal.”

The corn grain is low in ash, containing but 1.5 per cent, and extremely deficient in lime; this constituent forms only about 2.3 per cent of the ash, or 0.03 per cent of the grain. It is thus apparent that corn alone forms an incomplete ration for growing animals using grain alone, such as swine.

Corn is a shallow rooted crop and requires liberal manuring. It has the advantage, however, of a late summer growth, so that it has the opportunity of assimilating the nitrates produced during the hot season. Fresh farm manure should be applied to corn, as to most of the cereals, at the rate of 8 to 10 tons per acre.

Rice has been estimated to be the chief food of over one-half of the human race. It differs from the other grain crops in re-

quiring a warm climate and abundance of water, hence it is usually grown under irrigation. When so grown it yields two crops and requires liberal manuring. Since nitrification is suppressed on rice land, nitrates are very effective with this crop. Composted manures are used for the crop in China and Japan.

Rice grain is extremely low in ash, fiber and fat, and contains but about 7.4 per cent of protein. It is essentially a carbohydrate food, nearly 80 per cent of it being starch. The rice of commerce is a product of a milling process which removes the outer husk from the grain and yields as by-products, rice polish and rice bran. The former is fine and floury and much richer than the grain in ash, protein and fat, while the latter is a coarse material high in percentages of ash and fiber. The two by-products are usually mixed and sold as rice-meal, or rice-feed. Like wheat, and in contrast to most of the other grains, rice carries a large share of its phosphorus compounds in the outer coatings, which makes possible a considerable recovery of phosphoric acid with the manure produced from rice feeds.

Leguminous seeds differ chiefly from the seeds of cereals by a higher content of protein and a correspondingly lower content of carbohydrates. This does not involve, as already pointed out, a heavy demand upon the soil supplies of nitrogen. Protein formation in these crops, however, places a considerable tax upon the ash constituents of the soil. In some cases the carbohydrate material of these grains has been found to consist chiefly of galactans, a class of compounds already discussed under the "poly-saccharides" of the plant. Liberal supplies of phosphoric acid, lime and potash are required for these crops. A number of legumes produce seed which form a considerable bulk of the total crop. This is true of the soy-bean, horse-bean and cowpea. The several varieties of the true bean and the pea are the only seeds, however, of much commercial importance. The soy-bean and peanut seeds are distinguished by high percentages of fat, amounting to about 17 and 45 per cent in the grains, respectively.

Beans thrive best on clayey soils, well stocked with lime, potash and phosphoric acid. Several varieties are consumed, green or mature, as vegetables and are valued for their high protein content. The soy-bean was introduced from Japan and soy-bean meal finds some use as an animal feeding-stuff. It resembles the bean in its habits of growth.

Peas require much lime, and on rich soils they tend to produce luxuriant vines at the expense of seed. The fresh seed is prized as a vegetable and cured peas are valuable for pig feeding. It may be said that the leguminous crops in general thrive on soils poor in nitrogen but well supplied with the other elements of fertility.

Cotton-seed is one of several miscellaneous seeds of agricultural value. The seed is enveloped by the lint of the pod, or "boll," of the plant. American cotton yields about 300 pounds of lint and 600 pounds of seed per acre. The seed is rich in phosphoric acid, nitrogen and potash and the crop requires manurial applications of these constituents in the order given. Cotton-seed oil is extracted from the seed by pressure and also by the use of naphtha as a solvent. The outer coating, or hull, of the seed is generally removed previous to pressing, in which case the residue is known as "decorticated cotton cake," or, when ground, as "cotton-seed meal." A high proportion of hulls produces a dark colored meal and lowers its digestibility and food value. The meal is somewhat valued for feeding because of its high protein content, but because it contains some toxic substance, its use is necessarily restricted. It is also used as a fertilizer, supplying nitrogen in a form gradually available to the crop. Incidentally, it supplies considerable amounts of potash and phosphoric acid.

Flax seed, or linseed, thrives under much the same environment as that required by wheat. Where grown for fiber, the crop requires a moist, temperate climate, such as is found in Ireland, the northern United States and Canada; but seed production requires warmer climates. The crop produces an ave-

rage yield of about 850 pounds of seed and 2000 pounds of straw. Flax requires considerable amounts of phosphoric acid, potash and lime, with sufficient nitrogen to induce vigorous growth.

Linseed resembles cotton-seed in composition, but contains about one-half as much fiber and about 10 per cent more fat, having 30 to 40 per cent of the latter ingredient. The oil is obtained as from cotton seed, the ground residue from the crushing method being known as "old process" linseed meal, or "oil meal," while that obtained by solvents is known as "new process" meal. "Old process" meal carried 8 to 12 per cent of fat, while the new process of extraction leaves only 2 to 4 per cent of this constituent. The oil obtained from flax seed of the region about the Baltic Sea in Europe is preferred in the paint industry because of its great absorbing power for oxygen. Linseed meal is a valuable high-protein food for stock.

Hempseed is obtained from a crop resembling flax in its utility both for fiber and seed. It grows best in a temperate climate and resembles corn in its requirements of the soil. Hemp yields 500 to 1500 pounds of fiber and the same range of seed per acre. The seed is used as poultry food and the oil obtained from it is sometimes used to adulterate linseed oil.

Buckwheat has much the same composition as wheat. It has the advantage of thriving upon comparatively light, poor soils. It finds limited use in animal feeding and as human food.

Rape seed is sometimes grown for the production of "rape oil" or "colza oil." It yields over 40 per cent of this fat. The residue of the feed is used as manure, because it lacks relish as a cattle food. Rape belongs to the same plant family as the turnip and closely resembles it in manurial requirements.

The castor bean is the seed of a plant grown in some localities as a crop, in others for ornamental purposes, while in some cases it is looked upon as a weed. In the temperate zone it is an annual, but in the tropics it is a perennial tree of considerable size. It is an adaptable plant but thrives best on rich, sandy soils. The seed is valued for oil, which it contains to the extent

of 50 per cent. This oil finds application medicinally and as a lubricant. The residue of the seed is suitable for manure, but cannot be used for feeding because of its poisonous properties, due to a powerfully toxic protein, known as "ricin."

Sunflower seed is produced in yields of about 50 bushels per acre. The dry seed contains 20 per cent of an oil sometimes used as a substitute for olive oil. It also contains 30 per cent of fiber and 16 per cent of protein, the latter giving to the seed and its residue some value as poultry and cattle feeds. The crop produces heavily on soils high in fertility.

Hays or fodder crops include true hays which are cut at the blossoming or early seeding stage, and in which the stems so predominate in bulk as to make them practically straw crops. They have, in fact, the same general composition and food requirements as the cereal grains, irrespective of seed production. Under this class also fall the cereal grains, such as barley or oats, when cut while succulent for soiling purposes or hay making, and corn and other crops cut for silage. These differ from the cereal straws as a result of their comparative immaturity. The leguminous plants in this rôle differ from the corresponding legumes raised for seed in the same manner as indicated for cereal plants. They are cut at an immature stage of growth when the foliage far outweighs the seed in amount and importance. The *true hays* of importance are comparatively few in number.

Timothy is perhaps most commonly grown, alone or associated with clover. It is representative of the true grasses, as a class, being high in fiber, comparatively low in protein, and rich in potash and silica. It is shallow rooted and dependent upon liberal manuring. It grows best on peaty soils and hence is favored by heavy applications of farm manure. The application yearly per acre of 90 to 180 pounds of nitrate of soda, 300 to 600 pounds of bone meal and 70 to 140 pounds of chloride or sulphate of potash has been recommended as a fertilizer treatment.

Red top, Hungarian grass, Kentucky blue grass or June grass, orchard grass and similar hay crops resemble timothy in

their feeding habits and composition and require similar manuring in proportion to their yield.

Meadow hay and pasture grass are usually a mixture of plants, the predominant members of which are among the grasses already described, or others closely related to them. The peaty nature of the surface soil in permanent meadows is attributed to the decay of the shallow seated root system. This condition favors nitrification, which tends to exhaust the lime by the leaching of nitrate of lime from the soil. Such crops are therefore generally responsive to applications of lime, which may either be applied as limestone, burned lime, or in combination with phosphoric acid, as basic slag. Heavy dressings with farm manure or commercial fertilizers tend to drive out the valuable clovers and other leguminous plants and replace them with coarser growths. This is partly due to the production of an acid soil, which may be restored to normal condition by applications of wood ashes or lime. Yearly applications of plant food should be made to these permanent crops.

Cereal hays are made by cutting the crop when the grain is in the milk stage and just preceding the most active migration of nitrogen and ash constituents to this part of the plant. The nutrient compounds are then distributed generally through the plant and their digestibility is less depressed by cellulose compounds than is the case at maturity. The maximum production of tissue, especially desirable with these crops, will be promoted by liberal applications of nitrogenous manures.

Barley, oats, millet, sorghum and other cereals, which produce the more nutritious straws, are utilized for hays. They may be made to produce enormous yields, but at the expense of much plant food. Under such conditions, they must be considered as particularly exhaustive crops requiring heavy manuring.

The leguminous hays, while comparatively independent of manurial supplies of nitrogen, are sometimes benefited in early stages of growth by the application of soluble forms of nitrogen. This produces a plant of increased vigor and promotes further

assimilation of food. These crops feed heavily upon lime, potash and phosphoric acid. This fact is to be attributed largely to their extensive root systems, drawing from a wide range of soil for a large production of dry matter. As a consequence, these crops are especially benefited by the inorganic constituents of manures.

The reappearance of clover in limed meadows is a commonly observed indication of the value of this fertilizer. Wood ashes benefit these crops chiefly by reason of their content of lime and potash. The following fertilizer ration per acre has been recommended for clover and alfalfa: 40 pounds of nitrate of soda or 1 ton of farm manure; 500 pounds of bone meal; 150 pounds of muriate or sulphate of potash, or 1500 pounds of wood ashes: 1 to 3 tons of ground lime-stone, as required.

Ensilage is properly a hay crop. It is principally prepared from corn, although sorghum, millet, clover, cow peas and other succulent crops have been so treated. The production of good silage depends upon careful exclusion of the air. Under this condition the mass undergoes changes involving the consumption of oxygen and production of compounds not previously existing in the fresh material. The temperature of the mass rises and reaches its maximum in two or three days. These changes were once thought to be due chiefly to organisms producing alcohol, lactic and acetic acids, and other products of fermentation. Babcock and Russell, as a result of their studies on silage, have concluded that bacteria are not the essential cause of the changes within the silo, but are probably deleterious and exert their influence only in the production of objectionable putrefactive changes. These investigators further conclude that the changes in the silo are chiefly due to the respiration of living plant cells. This process either may involve the oxygen confined in the air spaces of the ensiled material, in which case it is known as "direct respiration," or it may utilize only the oxygen of compounds in the plant tissue, this process being known as "intra-molecular respiration." Both forms of activity cease with the death of the plant

cells. Hence, the more mature the corn when ensiled, the sooner these changes and the losses incident to them, cease. This theory is in harmony with the practical experience that rather mature corn produces superior ensilage. Maximum yield of material and the production of good silage are secured by selecting the corn when in a glazed state.

Chemical changes in the silo entail a loss of dry matter, the amount of which is dependent upon the care with which air is excluded. In the majority of cases investigated this loss has been from 15 to 20 per cent of the dry matter of the fresh crop and in some cases it has reached 40 per cent. King states that the loss need not exceed 4 to 8 per cent for corn and 10 to 18 per cent for clover. In 64.7 tons of silage packed in a silo, tightly lined with galvanized iron, he found an average loss of 6.38 per cent. The loss was estimated for eight separate layers in the whole silo and found to be 32.53 per cent for the top layer, 23.38 per cent for the next, and from 2.1 to 10.25 per cent for the others. The greater loss for the more exposed layers emphasizes the importance of oxygen in effecting a loss of dry matter, and the need of excluding air from the material by tightly packing it. In properly cured silage the loss of dry matter falls chiefly upon sugars, which are oxidized to organic acids and ultimately to carbon-dioxide and water. A part of the protein compounds is also altered, with the production of amino acids. In some cases over one-half of the nitrogen of the silage is present in the latter form. This is two to three times as much as the original fodder contains.

Since the sugars and proteins are compounds of high food value, the importance of restricting such losses in the silo is evident. Jordan estimates that a saving of three-fourths or even of one-half the average losses from 100 tons of corn as silage, would increase the farmers' food resources by an amount equivalent to from 5 to 7½ tons of timothy hay.

Root crops are generally gross feeders and quite dependent for their food supplies upon readily available materials.

✓ **The turnip** is a biennial plant which stores food the first season and produces seed the second year. The several varieties differ chiefly in the form and color of the root. The common turnip contains about 8 per cent of dry matter, which is largely starch. The rutabaga, or Swede turnip, contains more dry matter (about 13 per cent) and about 10 per cent of carbohydrates. The lower content of water than in the turnip promotes better keeping qualities. Turnips require an abundance of nitrogenous fertilizer. Investigations in this country indicate that the turnip family is less dependent upon readily available forms of phosphoric acid than other crops.

The beet is cultivated in several varieties. It is a deeper feeder than the turnip by virtue of its longer tap-root. The common red beet contains about the same proportion of dry matter and nutrients as the rutabaga. Mangel-wurzels, or field beets, are somewhat poorer than the red beet in dry matter, and noticeably so in nitrogen-free extract. The mangel produces a large root containing about 12 per cent of dry matter. The sugar beet is a smaller variety of the mangel. It contains more dry matter (13 to 19 per cent) than the other roots, most of which is sucrose. The production of beet sugar in Europe alone for 1903-1904 was estimated at about six million tons, or nearly twice the world's production of cane sugar. These root crops do best on deep, loamy soil, in rather warm, damp seasons, except that the mangel and sugar beet require rather dry fall weather. Mangels are probably the most exhaustive farm crop and require heavier manuring than the other roots, 12 to 14 tons of manure per acre being a common application. They are less dependent than turnips upon phosphate fertilizers, but respond generously to applications of nitrate of soda (about 200 pounds per acre). This crop is also benefited by the addition of common salt. The production of large roots is sometimes objectionable because they contain much more water than small ones. This is true with the sugar beet, where a high production of sugar is desired. Heavy manuring is therefore avoided and the crop is thickly sown. The

following manuring per acre is recommended for sugar beets: 3 tons of stable manure, 300 pounds of acid-phosphate, 140 pounds of sulphate of potash. The soil should be fairly stocked with lime.

The **potato** is a surface feeder and must be liberally manured to secure good yields. This crop contains 20 per cent of dry matter, which is mostly starch. It is a staple human food and is also fed to stock. In Europe, one of the principal uses for the potato is for the manufacture of alcohol. Stable manure appears to favor growth of scab and should be applied to a preceding crop. Chloride of potash is also said to be injurious to this crop. The fertilizer recommended per acre is: 225 pounds of sulphate of ammonia, 500 pounds of acid-phosphate and 200 pounds of sulphate of potash.

Fruit crops present peculiar manurial requirements, especially with relation to perennial growths. The composition of the 20 per cent of dry matter in common fruits is principally of carbohydrate nature (invert sugar, sucrose, cellulose, pentosans and pectose) with small amounts of organic acids, ash and nitrogen compounds. Green fruit contains starch, which is converted to sugar in the ripening process. The production of these compounds creates special demands for potash. Phosphoric acid and nitrogen are required in smaller amounts, except by the plum, an average crop of which removes 128 pounds of nitrogen per acre. The strawberry, blackberry and similar fruits will produce the best yields when a vigorous cane growth is induced by liberal manuring. They thus respond most markedly to applications of liquid manure. The fruit of trees draws its nutrients from an extensive woody growth and volume of sap, but these sources must be reinforced to keep the trees in vigorous bearing condition. Light yearly applications of farm manure or complete fertilizers are recommended for these crops.

Forest growth presents practically the same demands on fertility as do fruit trees, but as has been pointed out, this demand

is practically covered by a continuous return of plant food from this crop to the soil.

The miscellaneous crops, grown chiefly for the truck market, give cash returns which justify the expense of "forcing" rations of plant food. Such rations should include liberal amounts of nitrogen. Tobacco should receive some nitrogen and a liberal supply of potash, with phosphoric acid in moderate amount. Too much nitrogen is to be avoided because of unfavorable effects on the quality of the tobacco leaf. Cotton-seed meal at the rate of 200 to 300 pounds per acre before planting is a favorable ration. Potash should be applied as sulphate (100 lbs.), as the chloride is injurious. Phosphoric acid should be applied at the rate of 200 pounds of acid-phosphate or 400 pounds of bone meal per acre.

Cabbages, as a market crop, are brought to harvest early and are improved in quality by heavy applications of nitrogen. Nitrate of soda or sulphate of ammonia at the rate of 300 pounds per acre in two or three top dressings is recommended in addition to general manuring.

No specific rules can be laid down for the application of fertilizers to each crop, because of the greatly variant conditions of soil and climate under which it must be grown. These factors, particularly the latter, exert a profound influence on the growth of plants. Each farmer must determine the requirements of his own conditions by the fertilizer tests described in the chapter on "Fertilizers."

Factors influencing the composition of the crop are: Stage of growth, exposure at harvest, fertilizers and environment.

The stage of growth has been shown to present marked differences in the feeding value of the straw of cereal plants. In the true hay crops the grain takes up most of the nutrients of the plant during the ripening period. This results in increased fiber content and decreased feeding value of the stems. The Connecticut Experiment Station gives the following composition of timothy at successive periods preceding ripening.

Composition of Dry Matter of Timothy.

Stage of growth	Ash	Crude protein	Crude fiber	Nitrogen free extract	Ether extract
	Per cent	Per cent	Per cent	Per cent	Per cent
Well headed out....	4.7	9.6	33.0	50.8	1.9
In full blossom.....	4.3	7.1	33.3	53.3	2.0
When out of blossom	4.1	7.1	33.8	53.3	1.7
Nearly ripe.....	3.6	6.8	35.4	52.2	2.0

It will be observed that the protein and ash of the hay decrease rapidly from the heading out stage, while the fiber increases at the later stages. The nitrogen-free extract at the later stages is probably less valuable than at the earlier periods of growth as a result of increased proportions of indigestible pentosans and similar compounds. Thus, while the hay crops increase in the quantity of dry matter to the end of the ripening period, they decrease in palatability and food value when harvesting is delayed too long. These conditions are more serious with legume hays, where a large percentage of protein is involved. This is shown in the following table on the composition of alfalfa hay published by the Kansas Experiment Station:

Composition of Dry Matter of Alfalfa Hay.

	Ash	Crude protein	Crude fiber	Nitrogen free extract	Ether extract
	Per cent	Per cent	Per cent	Per cent	Per cent
First stage (about 10 per cent in bloom)	10.45	18.50	32.20	27.29	1.56
Second stage (about ½ per cent in bloom)	10.28	17.21	35.37	34.00	1.05
Third stage (full bloom)	8.45	14.43	36.10	39.62	1.41

The decrease in protein at the last stage is marked. These data indicate that the most favorable mean between quantity and quality of crop will be secured by cutting grasses and clovers between early and full bloom.

With corn, conditions are different. Analyses at the Maine Experiment Station gave the following data:

Composition of Dry Matter of Corn Plant.

Stage of growth	Ash	Crude protein	Crude fiber	Sugar	Starch	Nitrogen free extract	Ether extract
	Per cent	Per cent	Per cent	Per cent	Percent	Percent	Percent
Very immature (Aug. 15)	9.3	15.0	26.5	11.7	.....	46.6	2.6
A few roasting ears (Aug. 28)	6.5	11.7	23.3	20.4	2.1	55.6	2.9
All roasting stage (Sept. 4)	6.2	11.4	19.7	20.6	4.9	59.7	3.0
Some ears glazing (Sept. 12)	5.6	9.6	19.3	21.1	5.3	62.5	3.0
All ears glazed (Sept. 21)	5.9	9.2	18.6	16.5	15.4	63.3	3.0

The material increase in starch and other digestible carbohydrates more than offsets the relative decrease in crude protein and is accompanied moreover by a decrease of crude fiber. Feeding experiments moreover have shown that mature corn is more digestible than the immature plant, both as fodder and as silage.

Exposure to the weather, particularly undue exposure to rainy weather, detracts from the value of the crop. This is due to the leaching away of nutrient compounds by the rain.

The following table from Bulletin 135 of the Kansas Station shows the extent of such losses from alfalfa hay, assuming, as is approximately true, that no fiber is lost. The hay was exposed during 15 days, during which time it was subjected to three rains amounting to 1.76 inches:—

Losses by Rain to 100 Pounds of Alfalfa Hay.

	Crude Ash	Crude protein	Crude fiber	Nitro- gen free extract	Crude fat	Total
Pounds in original.....	12.2	18.7	26.5	38.7	3.9	100.0
Pounds in damaged.....	8.7	7.5	26.5	23.0	2.6	68.3
Pounds lost.....	3.5	11.2	00.0	15.7	1.3	31.7
Per cent lost.....	28.7	60.0	00.0	41.0	33.3	31.7

Not only has nearly one-third of the total dry matter been lost, but over one-third of this loss has fallen upon protein, which is the most valuable constituent of the hay. For every pound of protein in the damaged hay, one and one-half pounds have been lost by exposure.

Curing processes may seriously affect the composition of crops. Alfalfa hay furnishes a striking example of this fact. When cut early, this crop bears 73 pounds of leaf for 100 pounds of stem. The leaf, however, is much richer in nutrients than the stem. Thus, for 100 pounds of each constituent in the stems, the leaves of an equivalent amount of crop in each case will contain of: fat, 450 pounds; protein, 250 pounds; nitrogen free extract, 135 pounds; crude fiber, 28 pounds. That portion of the crop especially subject to mechanical loss in hay making is therefore the most valuable as fodder.

Headden has estimated the mechanical loss of alfalfa in harvesting at 15 to 20 per cent of the dry crop. In extreme cases 60 per cent or more may be left on the field. This loss falls chiefly upon the leafy tissue. More valuable hay will be secured if the crop is cut between early and full bloom and handled to a minimum extent, than if it is allowed to become brittle by aging or over-curing at harvest and then excessively handled.

Fertilizers influence the composition of the crop to a limited extent, both by their amount and their nature. This effect has been observed principally with reference to the increase of pro-

tein formation by application of nitrogenous fertilizers. Pingree found that nitrogen applied to oats, in the form of dried blood, slightly increased the protein content of both grain and straw. At the Storrs (Conn.) Experiment Station, corn, oats and mixed grass (timothy, red top and Kentucky blue grass) were supplied with gradually increasing amounts of nitrogen, added to a uniform ration of potash and phosphoric acid. Within certain limits, the protein content of the corn and oat grains, oat straw, corn stover and grasses was increased, somewhat in proportion to the amounts of nitrogen supplied. Parozzani found that increased application of super-phosphates to corn resulted in a corresponding increase of total phosphoric acid in the seed. Investigation of the distribution of phosphorus in the seed showed that, while the amount in nuclein compounds remained constant, the amounts in the forms of lecithin and phytin were increased. Total nitrogen in the seed was not sensibly affected, but the proportion of true protein compounds was slightly increased and this increase was limited to a specific protein, namely, zein.

Such examples as these are limited. From an intimate knowledge of the long series of fertilizing experiments at Rothamsted, Hall is led to state that, "Although the composition and quality of the grain is affected by the amount of nitrogen supplied to the crop, it is really astonishing to find how small are the changes brought about by extreme differences in manuring." The effects may be more marked with other parts of the crop, but, quoting Hall further: "The crop reacts against variations in the composition of the soil and tends to keep its own composition constant. When also the time comes for the grain to be formed from the reserve materials already stored up in the plant, another attempt is made to turn out a standard product. Even on the Rothamsted plots, where the differences in the supply of nutrients are extreme and have been accumulating for 50 years, the composition of the grain changes more from one season to another than it does in passing from plot to plot."

Environment has been found to influence the composition of

the crop more than any other factor. The sugar beet has given valuable results along this line in experiments, conducted by Wiley in this country from 1900 to 1905. Beets were grown from the same seed at 12 experiment stations scattered from Kentucky to Wisconsin and from New York to California. At Utah, California and Colorado the crops were grown under irrigation. Chemical and meteorological records were carefully kept in all cases. As a result of this and similar investigations, Wiley concludes that the soil and fertilizers have only a limited influence and that temperature (or latitude) is the most potent element of the environment in the production of a beet rich in sugar. Excessive rain fall and irrigation affect the beet only incidentally by increasing the yield with a proportionate reduction in percentage of sugar, and dry tillage produces opposite effects. With these conclusions as a basis, there has been mapped for the northern United States a belt of country which presents optimum climatic conditions for the production of sugar beets.

Wheat has been tested in a similar manner and the results have been reported recently by Le Clerc. Crops were grown from the same seed at the apices of two great triangles; namely: Kansas, South Dakota and California; and Kansas, Texas and California. The results demonstrate that the same variety of wheat brought from different localities and grown side by side in one locality, yields crops of almost the same appearance and composition. On the other hand, "wheat of any one variety from any one source and absolutely alike in chemical and physical characteristics, when grown in different localities, possessing different climatic conditions, yields crops of very widely different appearance and very different chemical composition." Thus, with relation to protein, the constituent of most concern, the seed of Kubanka wheat grown in South Dakota in 1905 contained 13.03 per cent. The 1906 crop grown from this seed contained: in Kansas, 19.85 per cent of protein in the seed, in California, 9.68 per cent, and in South Dakota, 14.24 per cent. The seed from these localities grown in 1907 at California contained 9.70,

9.90 and 9.05 per cent of protein in the seed, respectively, while portions of the same seeds grown in South Dakota contained 14.24, 13.89 and 12.87 per cent of protein. The same condition obtained with Crimean wheat grown in the other triangle, Kansas uniformly producing the highest protein content in the grain and California the lowest. These results lead to the conclusion that a crop should be improved by selection in the region where it is to be grown, or that "seed should be selected from a region of similar climatic condition."

The author just quoted compared eight samples of Durum wheat grown in arid and semi-arid regions with seven samples of the same variety from humid regions. The seed from dry regions contained 17.23 per cent of protein. and that from humid regions, 13.75 per cent; and the samples weighed 30.3 grams and 33.5 grams per 1000 grains, respectively. Abundant water supply is thus productive of plump, starchy grains, while dry conditions produce a smaller grain richer in protein. This contrast is illustrated by the change in composition of Durum wheat grown in Mexico. The original seed contained 12.3 per cent protein. Grown under irrigation it produced seed of 11.1 per cent protein, non-irrigated, 17.7 per cent. Shutt has confirmed these data with wheat grown on irrigated and non-irrigated soil at Manitoba, Canada. Lawes and Gilbert had previously observed at Rothamsted that hot, moderately dry seasons produced the best quality of wheat.

Sweet corn has been similarly tested by Wiley for several successive years. The results have shown that the content of sugar is less influenced by temperature than in the case of the sugar beet. The ripening crop was followed along the Atlantic coast from Florida to Maine. Contrary to the results with the sugar beet the higher average content of sugar appeared to be found in the warmer climates. The lower temperatures of the North, however, retard the ripening process and render the corn succulent for a longer period than does the warm climate of the extreme South. Wiley concludes that the amount and distribu-

tion of rainfall is the most important factor affecting the edible quality of green sweet corn, and that the favorable effects of moderate, well distributed rain-fall indicate that the northern states will continue to produce the best crop outside the irrigated districts. But no special area for sweet-corn growing can be mapped as has been done in the case of the sugar beet.

Crop rotation should be rationally based upon the varying demands of crops for plant food and the characteristic feeding habits of individual species of plants. When the plant food of the surface soil has been exhausted by such shallow rooted crops as corn, grasses and turnips, they should be followed by deep rooted crops, such as wheat, mangels, or alfalfa. Not only will the latter crops obtain their supplies of food from the lower layers of the soil, but they leave a portion of it at the surface in roots and stubble, from which it becomes available to succeeding crops. No more striking example of this fact is furnished than that of alfalfa. According to Headden, the roots and stubble of alfalfa to a depth of 6½ inches contain approximately 2.86 tons of dry matter per acre, having the following constituents: total ash 172 pounds; phosphoric acid 24 pounds; sulphur trioxide 9 pounds; lime 50.5 pounds; chlorine 6.5 pounds; magnesia 15.15 pounds; potash 44.5 pounds; and 104 pounds of nitrogen. Reference to the table in the Appendix which gives "Plant food removed by crops," shows that the stubble of alfalfa alone, places in the surface soil as much plant food as is removed by total cereal crops.

The waste tops of the mangel crop can also restore to the soil as much food as is required by an average grain crop. Not only will these crops restore fertility to the surface soil, but their deep root systems, and the deep thorough tillage demanded by them, will benefit the physical condition of the soil when they are grown in rotations.

Increase of soil nitrogen is the most valuable effect produced by legume crops grown in systems of rotation. In this connection the work of Shutt in Saskatchewan, Canada, is of interest.

He compared a virgin soil of that province with one that had been continuously cultivated to cereal grains or fallow for 20 years. The cultivated soil contained 0.253 per cent of nitrogen (to a depth of 8 inches) and the virgin soil contained 0.371 per cent. This difference represented a loss of 2200 pounds of nitrogen per acre by the system of cultivation practiced. Investigating the possibility of restoring nitrogen to the soil, Shutt grew common red clover upon a poor sandy soil, cutting the crop twice yearly and leaving it upon the soil. At the end of each second season the crop was turned in and the plot re-sown the next spring. In five years of this treatment the soil gained over 300 pounds of nitrogen per acre to a depth of four inches, despite inevitable losses by nitrification and leaching.

The effect of the growth of clover on succeeding crops was demonstrated by Shutt in field experiments. Two series of plots were used, on one of which clover was compared with wheat, while on the other oats and clover were compared with oats. The first series will be described. On one plot, clover was sown alone and one cutting made and removed. The crop was turned under in the following spring. On the other plot, wheat was grown and harvested as usual. The effect of this treatment was observed on grain and root crops for three succeeding years, with the following resultant data:—

Increase of Crop Due to Growth of Clover.

1900	1901			1902			1903		
		Tons	Lbs.		Bush.	Lbs.		Tons	Lbs.
Plot A: Clover.....	Corn	27	1,760	Oats	75	10	Sugar beets	22	600
Plot B: Wheat.....	Corn	19	1,280	Oats	51	26	"	8	1,260
Increase due to clover	Corn	8	480	Oats	23	18	"	13	1,340

This effect was obtained without a sacrifice of the crop and must have been chiefly due to the nitrogen supplied by the stubble and second growth of the clover.

The distribution of nitrogen in the legume crop bears an important relation to its proper use in rotations. Shutt gives the distribution of nitrogen between the roots and stubble and the tops of legumes as follows:—

Nitrogen in Legumes.

Legumes: One season's growth	Nitrogen in parts of crop (Pounds per acre of crop)	
	In tops	In 9 in. depth of root and stubble
Clover, common red.....	90	48
Clover, mammoth.....	82	48
Clover, crimson.....	85	19
Alfalfa.....	75	61
Hairy Vetch.....	129	18
Soy bean.....	82	13
Horse bean.....	63	15
Pea.....	119	10

The proportion of the total nitrogen of the crop contained in the roots of common red and mammoth clovers and alfalfa indicate the effectiveness of the residues of these crops as sources of nitrogen, when they are grown in rotations and the crop harvested. The figures for alfalfa are probably much below the average and fail to do justice to the crop. The condition is different with shallow rooted legumes. Thus, with the vetch and pea, a large supply of nitrogen in the tops is correlated with a comparatively small amount in the roots. Marked benefit from these crops in rotations can be secured only where the whole growth is turned in. Snyder states that the nitrogen content of the soil can be maintained and even slightly increased when clover is grown two years in a five course rotation with grains and timothy to which farm manures are applied.

CHAPTER IX

THE ANIMAL BODY.

The elements found in animal tissue are the same as those found in the plant world, and while sodium and chlorine are considered by some as non-essential for plant development, in the formation of the animal's tissue they are indispensable. Fluorine and silicon are also always found in the animal body, but are not known to be absolutely essential for life or growth. Fluorine occurs in small quantities in the teeth and bones, and silicon in the hair, wool and feathers.

The compounds forming the animal body are many and very complex and only a brief survey of the principal ones can be given here.

The constituents of the animal body may be divided into:—

(1) *Inorganic compounds*, including water, various acids and numerous salts; some are in the solid state, as the calcium phosphate of the bone; others are in solution as the sodium chloride of the blood.

(2) *Organic compounds*,

	Simple-proteins, amino-acids, etc.	Conjugated-proteins	Derived proteins
(a) Nitrogenous.....	Albumins Globulins Albuminoids Amino-acids Amides	Nucleo-proteins Phospho-proteins Glyco-proteins	Proteoses Peptones
(b) Non-nitrogenous...	Fats Carbohydrates		

Of the inorganic constituents, by far the largest part is contained in the bones. In fat animals 75 to 85 per cent of the total ash constituents of the body are found in the bones. Bone

ash consists of phosphate of calcium, with a small quantity of carbonate of calcium and phosphate of magnesium. In muscle by far the most abundant ash constituent is phosphate of potassium. Potassium salts are also abundant in the "yolk" of unwashed wool and in the sweat of horses and other animals. Blood, on the other hand, always contains a preponderance of sodium salts.

The nitrogenous substances constituting the animal body are extremely varied in character and properties and it would be impossible in a book of this kind to attempt to describe them in detail. The albumins and globulins form the substance of animal muscle and nerve, and the greater part of the solid matter of blood. They are undoubtedly of the greatest importance in the animal economy. The albuminoids form the substance of skin and sinew, of all connective tissue, and also the protein material of cartilage and bone. Keratin, the principal protein of horn, hair, wool and feathers, belongs to this class. The remarkable difference in the properties of the protein, keratin, and the protein, serum-albumin, lies in the internal structure of their respective molecules.

The nucleo-proteins always contain phosphorus and are contained in every cell. They are of special importance in all life processes. The phospho-proteins are represented in the animal kingdom by the important nitrogenous body found in milk, namely, casein. This class of bodies is also represented in the yolk of the egg, in the form of the protein, vitellin. These phospho-proteins contain phosphorus just as the nucleo-proteins do, but differ in their internal structure from those bodies. The glyco-proteins are compounds of a protein molecule with a substance, or substances, containing a carbohydrate group. In solution, they are characterized by being ropy and mucilaginous and are contained in the mucus secretions of many membranes and glands of the animal.

The proteoses and peptones are found in the digestive tract of the animal and are derived from the proteins of the food by the

action of the proteolytic enzymes of the alimentary canal. They are water-soluble bodies.

All of these protein bodies contain very similar amounts of nitrogen—namely, 15 to 18 per cent. Besides the above nitrogenous materials constituting tissue, the animal juices contain a variety of nitrogenous substances such as creatin, creatinin, sarcosine, etc., but with which we are not concerned.

The amino-acids are simple nitrogenous bodies formed during the process of digestion from the proteins of the food and are believed to be the building materials out of which the animal reconstructs its own tissue protein.

The amides, principally represented by urea in the urine, are the simple nitrogenous waste products of the tissues. In the cow, 85 to 95 per cent of the total nitrogen in the urine is in this form.

The fats occurring in the animal body are principally stearin, palmitin and olein. Stearin predominates in hard fats and olein in more fluid fats. They are identical in composition with these same materials described in the chapter on the plant. Lecithin, a complex fat containing both nitrogen and phosphorus, is also widely distributed in animal tissue.

Carbohydrates. The important carbohydrate of the animal body is glycogen, found in considerable quantities in the liver and in smaller amounts in the muscular tissue. It resembles starch in its constitution. At no time does it constitute an appreciable proportion of the animal's weight. In this respect animals differ from plants. In the latter the stored reserve material is usually starch, while in the animal, fat is the reserve material. The glycogen found in animal tissue has had its origin from the various carbohydrates of the feed. These have been absorbed from the digestive tract largely in the form of dextrose, one of the simpler sugars, and from which glycogen has been rebuilt.

Composition of farm animals. The amounts of water, nitrogenous matter, fat and ash constituents present in a large num-

ber of animals, have been determined by Lawes and Gilbert at the Rothamsted Station. The following table shows the percentage composition of the whole bodies of various farm animals. The fat pig was one grown for fresh pork, not for bacon. Store animals are those in good flesh, but not fat.

Composition of Farm Animals.

Animal	Water	Fat	Protein	Ash	Content of stomach, etc.
	Per cent	Per cent	Per cent	Per cent	Per cent
Fat calf.....	63.0	14.8	15.2	3.8	3.2
Half fat ox.....	51.5	19.1	16.6	4.6	8.2
Fat ox.....	45.5	30.1	14.5	3.9	6.0
Fat lamb.....	47.8	28.5	12.3	2.9	8.5
Store sheep....	57.3	18.7	14.8	3.2	6.0
Half fat sheep.....	50.2	23.5	14.0	3.2	9.1
Fat sheep.....	43.4	35.6	12.2	2.8	6.0
Store pig.....	55.1	23.3	13.7	2.7	5.2
Fat pig.....	41.3	42.2	10.9	1.6	4.0

It will be noticed that in nearly every case water is the largest ingredient of the animal body. The proportion of water is greatest in young and lean animals and diminishes toward maturity and especially during fattening. The proportion of nitrogenous matter and ash tends to increase as the animal ages, but diminishes during fattening. The half fat ox contains 6 per cent more water than the fat; the store sheep 14 per cent more than the extra fat, and the store pig 14 per cent more than the fat. The fattening process does not involve a replacement of the water already in the tissues, but the increase is much more largely dry matter. Because this increase during fattening is largely fat, the proportion of protein and ash in the dry substance of the fattened animal has decreased relatively.

The largest proportion of nitrogenous matter and ash are found in the ox, the smallest in the pig. The difference in the proportion of ash is chiefly due to the wide difference in the

proportion of bone in these two animals. Fat is found in greatest quantity in the pig and is least in the ox.

The following table shows the quantity of nitrogen and the principal ash constituents in the fasted live weight of the animals analyzed at Rothamsted. The table is based upon a weight of 1000 pounds for each animal. The table also includes milk, wool and eggs, and supplies information as to the loss a farm would sustain by the sale of animal products. According to this table, the ox contains, in proportion to its weight, a larger amount of nitrogen and a much larger amount of lime and phosphoric acid than either the sheep or pig. Of all the animals raised on the farm, the pig contains the least of all the important ash constituents.

Attention should be called to the large amount of potash in unwashed wool. It is possible for the fleece to contain more potash than the whole body of the shorn sheep. The fleeces of four Hampshire Down sheep, analyzed at Rothamsted, contained about 6.5 per cent of nitrogen and 2 to 3 per cent of ash.

Ash Constituents and Nitrogen in 1000 Pounds of Various Animals and the Same Weight of Their Products.

Animal	Nitrogen	Phosphoric acid	Potash	Lime	Magnesia
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Fat calf.....	24.6	15.3	2.0	16.4	0.8
Half fat ox.....	27.4	18.3	2.0	21.1	0.8
Fat ox.....	23.2	15.5	1.7	17.9	0.6
Fat lamb.....	19.7	11.2	1.6	12.8	0.5
Store sheep.....	23.7	11.8	1.7	13.2	0.5
Fat sheep.....	19.7	10.4	1.5	11.8	0.5
Store pig.....	22.0	10.6	1.9	10.8	0.5
Fat pig.....	17.6	6.5	1.4	6.3	0.3
Wool (unwashed)...	54.0	0.7	56.2	1.8	0.4
Wool (washed).....	94.4	1.8	1.9	2.4	0.6
Milk.....	5.7	2.0	1.7	1.7	0.2
Hen's eggs.....	20.0	4.2	1.7	60.8	1.0

Fattening an animal increases the proportion of butcher's meat while at the same time it materially modifies its composition. Jordan gives the proportion of dressed carcass in per cent as follows:

	Ox	Sheep	Swine
Lean animal.....	47	45	73
Fat animal.....	60	53	82

The composition of the increase of an animal varies much under different circumstances. The increase of a young growing animal will contain much water, protein and ash; that of a mature fattening animal will consist chiefly of fat. From this it follows that a larger proportion of protein and ash is needed during the earlier periods of growth; but, because of the larger proportion of water, a smaller amount of food is required to produce one pound of gain.

The composition of the increase of oxen, sheep and pigs, when passing from the "store" to the "fat" condition has been calculated by Lawes and Gilbert.

Percentage Composition of the Increase While Fattening.

	Water	Protein	Fat	Ash
	Per cent	Per cent	Per cent	Per cent
Sheep.....	22.0	7.2	68.8	2.0
Oxen.....	24.6	7.7	66.2	1.5
Pigs.....	28.6	7.8	63.1	0.5
Average.....	25.1	7.6	66.0	1.3

The increase during the fattening stage of growth is seen to contain 8 to 9 parts of fat for one of nitrogenous matter.

Important parts of the animal body. Blood consists of a colorless liquid—plasma—holding in suspension numerous small solid bodies, the red and white corpuscles. The red corpuscles give the blood its characteristic color. These corpuscles have a definite structure and make up 30 to 40 per cent of the blood.

When taken from an animal the plasma quickly deposits one of its protein constituents, fibrin, which, entangling the corpuscles, causes them to separate as a clot from the yellowish liquid—the serum. Blood plasma is therefore the liquid portion of fresh blood, while blood serum is the liquid portion after clotting. The latter differs from the former by having lost its fibrin and a portion of its lime, magnesia and phosphoric acid.

Blood is the nutrient fluid of the body. It is the source of nourishment for all the cells. Out of its ingredients the tissues are built. It contains about 81 per cent of water, so that it easily holds in solution whatever soluble nutrients are furnished it from the digestive tract.

The 19 per cent of solids consists of the following materials: 10 per cent of haemoglobin; 7 per cent of proteins; about 1 per cent of ash; the remaining 1 per cent consists of fats, sugars, lecithin, etc. The color of the blood is due to haemoglobin. This body is extremely complex in composition and contains about 0.4 per cent of iron. Haemoglobin is a dark purplish-red colored substance. It readily combines with oxygen to an oxy-compound which is bright red in color. The haemoglobin plays an important part in respiration as the carrier of oxygen to the tissues.

The red corpuscles consist of circular, bi-concave discs, though their shape and size vary in different animals. They are largest in reptiles. In man the average diameter of a blood corpuscle is about $1/3200$ of an inch, and its thickness about $1/12800$ of an inch. These corpuscles contain the haemoglobin, the coloring matter of the blood. When they are treated with water or ether they loose their coloring matter and leave a nitrogenous residue which retains the shape of the original corpuscles.

Bones consist of an earthy frame work composed mainly of calcium phosphate, permeated by an albuminoid, called ossein, and by nerves, blood vessels, etc. In the hollow center of many bones is the marrow, which consists of fats and proteins. The relative proportion of mineral and organic matter in bones varies considerably. The amount of mineral matter in the green bone

varies from 40 to 60 per cent. No definite percentage can be given, as the amount, up to a certain limit, will vary with the supply of lime and phosphoric acid in the food and also with the source of the bone.

The ash of bone is not entirely phosphate of lime, but contains in addition carbonates, fluorides, chlorides and magnesia. The following analysis of bone ash is given by Ingle:

Calcium phosphate.....	86.0 per cent
Magnesium phosphate.....	1.0 "
Calcium, as carbonate, chloride and fluoride...	7.3 "
Carbon dioxide.....	6.2 . "
Chlorine.....	0.2 "
Fluorine	0.3 "

Muscular tissue consists largely of proteins and water, but contains in addition small quantities of fat, glycogen (animal starch), and certain nitrogenous extractives, such as creatin, creatinin, xanthin and guanin. Small quantities of dextrose are also contained in muscle tissue. The ash of muscle consists largely of potash and phosphoric acid compounds, but there are also present small amounts of sodium, magnesium, calcium, chlorine and iron. Muscle usually contains about 75 to 80 per cent of water, and 20 to 25 per cent of solids.

When a muscle does work, the glycogen and sugar are burned at an increased rate and the blood, which bathes the muscle, receives an increased proportion of carbon dioxide. Fats are also sources of mechanical work for the muscle. When fats and carbohydrates are available for consumption, the nitrogenous waste of the muscle is not increased by exercise, and only the normal amount of waste nitrogenous products, as urea, uric acid, etc., appear as the result of the life processes.

Fatty tissue is made up of relatively large, oval, or spherical cells. These cells consist of a nitrogenous membrane, filled with fat, which during life is fluid. The fats, which resemble in constitution the vegetable oils already described, are chiefly composed of stearin, palmitin and olein. The fat cells may be

found deposited between the fibers or cells of muscular tissue, or may constitute almost the entire mass of adipose tissue. When the latter is the case, the fatty tissues will consist of water, membrane and fat in about the following proportions:—

	Ox	Sheep	Pig
Water (per cent).....	9.96	10.48	6.44
Membrane “	1.16	1.64	1.35
Fat “	88.88	87.88	92.21

Fat is stored in the body as a reserve material from which the animal can draw in time of scarcity of food. It is the most concentrated form in which energy is stored in the animal.

Connective tissue, of which tendons, ligaments, cartilage and skin are mainly composed, consists of substances which yield gelatine when heated with water. These are the albuminoid compounds and constitute the framework of the animal tissues. They are to the animal body what cellulose is to the vegetable kingdom. They are only slightly attacked by acids and alkalies and are insoluble in water and salt solutions. Several different bodies have been recognized, among which are elastin, collagen and keratin. The first is the principal constituent of the elastic tissues and contains but traces of sulphur. The second, collagen, constitutes the foundation of cartilage and may be extracted from these tissues with hot water. The product which goes into solution is called gelatine and solidifies on cooling. It contains about 0.6 per cent of sulphur. The third substance, keratin, is the main constituent of hair, horn, hoof, feathers and wool, and contains 4 to 5 per cent of sulphur. It is insoluble in water, but by heating with water under pressure to 150-200° C. it may be rendered soluble and then constitutes glue.

Processes of nutrition. We have seen that the food of plants is of the simplest character and from such simple materials as carbon dioxide, nitrates, certain other inorganic salts and water, a plant is able to construct a great variety of complex compounds. It accomplishes these surprising transformations by a consumption of energy (sunlight) external to itself. An animal has no

such power. The animal tissues are built up from the complex substances existing ready-formed in the food. The animal derives no aid from external energy. The temperature of the animal body (about 100° F.) is maintained by heat generated within the body and by the combustion of the material consumed as food. The energy by which all the mechanical work of the animal is performed, comes from the same source. The source of heat and force in the animal is thus purely internal.

It is apparent from what has been said that the food of animals has duties to perform which are not demanded of the food of plants. In plants the food chiefly provides material for building up the vegetable tissues. In the animal, besides constructing tissue, the food must furnish the means of producing heat and performing mechanical work; to accomplish this result, it must be burned in the animal body.

Functions of food constituents. The solid ingredients of vegetable food may be classed, as (1) proteins; (2) fats; (3) carbohydrates; (4) salts. Besides these general classes of food constituents, we have in immature vegetable products, as hays, roots, etc., a fifth class—the amino-acids and amides—which also take part in animal nutrition. They are the simple intermediary nitrogenous substances, formed from the nitrates absorbed by the plant, and eventually take part in the construction of the complex proteins of seeds and plant tissue.

The proteins occurring in seeds, roots and other forms of vegetable food, have a general similarity in composition to those found in milk, blood, and flesh, but are by no means identical. From the proteins of the food are formed not only the proteins of the soft tissues of the animal, but also such a class of proteins as the albuminoids, which differ so materially in properties from the proteins of blood and muscle. It is also very probable that fat, a non-nitrogenous body, may be formed from protein. This is still a much disputed question and it remains for future investigations to definitely decide this point.

Proteins can also serve as a source of energy. In the case of

a dog eating exclusively a meat diet, probably a greater part of the protein eaten is not stored but is used as fuel. We see from this that the proteins can serve most of the requirements of the animal, a statement which cannot be made of any other food constituent. They are the true tissue builders.

An animal, even when not increasing in weight, will always require a certain constant supply of protein in its food to replace the waste of nitrogenous tissue, which is always going on even during rest. The cell proteins are constantly undergoing decomposition and reconstruction.

When the nitrogenous tissues of the animal, or the proteins consumed as food are decomposed in the body, the nitrogen they contain is largely excreted in the form of a simple nitrogenous substance, urea. This is eliminated by way of the kidneys in the urine. There are small quantities of other nitrogenous products, such as uric acid, creatin, creatinin, and in the case of herbivora, hippuric acid, voided in the urine, but they constitute but a small proportion of the total nitrogen eliminated. The urea produced is rich in nitrogen, containing about 46.6 per cent. It represents about one-third the weight of the protein oxidized.

The amides and amino-acids consumed as food are burned in the body and their nitrogen excreted as urea. It is very probable that they can, in part, take the place of proteins as tissue builders. In addition, by their combustion, they serve as sources of heat and force.

The fats are free from nitrogen. Those contained in food are similar to those found in the animal body. It appears possible for a vegetable fat to become deposited in the animal without essential change. Small deposits occur in every organ and cell. The fat reserves vary much in size, depending on nutritive conditions, so that no definite statement can be made regarding the fat content of the individual organs. The fat of the food is either burned in the animal system to furnish heat and mechanical energy or is stored up as reserve material. With their larger content of carbon and smaller proportion of oxygen, fats are less

easily oxidized than sugars and require a larger intake of oxygen for their combustion; but when oxidized they yield more heat per pound than any other food ingredient.

The carbohydrates of the food are chiefly starch, sugars, celluloses and pentosans. Various other non-nitrogenous constituents of food, such as the pectins, lignin and vegetable acids, are generally included under this title, though they are not, strictly speaking, carbohydrates. Carbohydrates form the largest part of all vegetable food. They are not permanently stored in the animal body, but serve when burned in the system, for the production of heat and mechanical work. If a fattening steer were consuming 16 pounds of digestible organic matter and gaining two pounds of live weight daily, the body increase and urine would contain not over 2.5 pounds of dry matter, leaving not less than 13.5 pounds to be oxidized, of which 12 pounds might consist of carbohydrates and fat, mostly the former.

The carbohydrates are also capable, when consumed in excess of immediate requirements, of conversion into fat. The well-recognized value of corn meal as a fattening food, a feeding stuff nearly seven-tenths of which consists of starch and similar structures, is a practical illustration of this truth.

The carbohydrates and fats are the natural fuel food stuffs of the body. They cannot serve for the renewal or upbuilding of tissue, but by oxidation they constitute an economical fuel for maintaining body temperature and for power to run the bodily machinery. Proteins may likewise serve as fuel, but this is apparently confined to a non-nitrogenous part of their molecule. When fats or carbohydrates are available the proteins of the tissue are not normally consumed for production of heat and force. Only when the former are lacking will the animal increase its protein metabolism and nitrogen output for purposes of maintaining the body temperature. A moderate quantity of protein supplied to a growing animal will thus produce a much larger increase of muscle when accompanied by a liberal supply of carbohydrates or fats. In this case, the non-nitrogenous constit-

uents of the food supply the demands for heat and work and the protein can be devoted to the rebuilding or increase of tissue.

If an adult animal receives the small amount of protein and salts necessary to repair the daily waste of tissue, it would be expected that the whole of the remaining wants might be met by supplying carbohydrates or fats. This is to some extent true; but a ration very poor in protein is not found to be consistent with real bodily vigor. There is some specific action of proteins not as yet understood. They appear to stimulate cell activity, a property not possessed by fats and carbohydrates.

The ash constituents present in food are the same as those found in the animal body. The animal simply selects from the digested ash constituents those of which it is in need. The tissue, the blood, digestive fluids, and the bony framework contain a variety of these bodies, which are as essential as any of the other substances considered for the building and maintenance of the animal body. Without lime and phosphoric acid there can be no bone formation, and the digestive juices would cease to be active if deprived of chlorine. A cow from which common salt is withheld will, in time, die. Not only must the growing calf have ash material for constructive purposes, but the mature ox must be supplied with them in order to sustain the nutritive processes. The milch cow, which stores combinations of lime, phosphoric acid, potash and other salts in the milk, must have an adequate supply of these materials. Nothing else can take their place. Lime and phosphoric acid, stored in abundance in the framework of the animal, may at times of deficient supply in the food, act as internal sources; but ultimately all ash elements must have been contained in the food.

Digestion. We have accepted so far without discussion the self-evident fact that the food is the immediate source of the energy and substance of the animal body. It is now necessary to consider the way in which the nutrition of the animal is accomplished. Digestion is the important process by which the food of an animal is rendered capable of being absorbed into the sys-

tem and utilized in building up or renewing the tissue of the body. Hay and grain cannot directly be transferred to the blood, but must first be brought into soluble and diffusible condition before they can pass out of the alimentary tract into the blood and lymph. This is accomplished partly by mechanical means, but mainly by chemical changes, which are produced chiefly by the action of bodies called enzymes.

Enzymes are a peculiar class of substances produced by living cells which constitute the various secreting glands. They are of unknown composition and are peculiar in that the chemical changes which they induce are the result of what is called catalysis, or contact. That is, during the solution of the food stuffs, the enzyme is not used up or destroyed, but by its mere presence sets in motion or quickens a reaction between two other substances. For example, the enzyme of the saliva causes the starch of the food to combine with water, with the result that the soluble sugar maltose, is formed. An enzyme that acts upon starch, for example, cannot act on proteins or fats. Some digestive fluids have the power of producing changes in different classes of food stuffs, but when this occurs, it is assumed to be due to the presence in the same fluid of different enzymes. Again, enzymes are sensitive to their environment, and a proper temperature and reaction must be maintained for their activity. The activity of saliva is extremely sensitive to the nature of the reaction and ceases when that becomes acid. Enzymes are thus seen to be more or less unstable substances, endowed with great power as digestive agents, but sensitive to a high degree and working advantageously only under definite conditions.

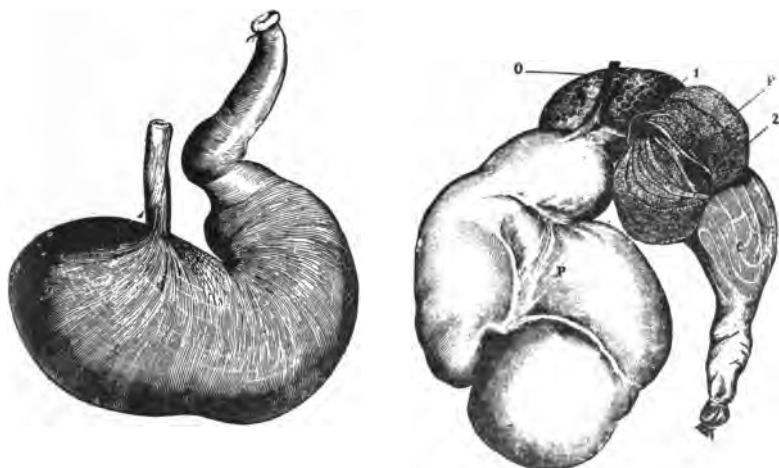
Digestion in the mouth. The first step is mastication, by which the food is subdivided and crushed by the action of the teeth and thoroughly mixed with saliva. This special secretion has its origin in several secreting glands, and from these this liquid is poured into the mouth through ducts, opening in the cheek under the tongue. Saliva is a highly dilute liquid of faintly alkaline reaction and contains an enzyme, *ptyalin*, which has

the power of bringing about the same changes as are produced by plant diastase, that is, the conversion of starch into the sugar, maltose. This change begins in the mouth and continues for a limited time in the stomach, or until the gastric secretions establish an acid reaction in the stomach contents. When this is established, salivary digestion ceases. The proteins and fats are not attacked by the salivary secretion.

Ruminants, whose feed usually contains much starchy material, secrete enormous quantities of saliva. It is estimated that oxen and horses secrete from 88 to 122 pounds daily. This serves the additional important function of properly preparing the food for swallowing.

Gastric digestion. The food after mastication passes down the gullet into the stomach. In the case of the horse and pig the stomach is a single sac, and true gastric digestion begins at once. In ruminants, as the ox and sheep, the stomach consists of four divisions, or sacs, and not until the fourth is reached, does gastric digestion proper begin. These sacs may be considered as enlargements of the oesophagus and primarily for the storage of the bulky materials consumed by these classes of farm animals. The four divisions are the paunch, honey-comb, many-plies and rennet, or what the anatomist has called the rumen, reticulum, omasum and abomasum. The capacity of these cavities in the ox is, on the average, not far from 50 to 60 gallons, about nine-tenths of the space belonging to the paunch. It is in the paunch that the food is first stored, only the finer portions being carried by what is known as the oesophageal groove to the third stomach, and finally from this compartment into the fourth and last division. From the paunch the food is returned to the mouth where it is more finely ground before passing to the fourth stomach for digestion. This is what is termed "chewing the cud." In the paunch salivary digestion probably continues, as well as other fermentations induced by various micro-organisms. Here possibly a partial fermentation of cellulose by bacterial enzymes begins.

When the food reaches the fourth stomach, it meets with the characteristic secretion of that organ, the gastric juice. This juice is secreted by glands located in the mucus membrane of the stomach. It is a watery fluid, containing various salts, as chlorides and phosphates of calcium, magnesium, sodium and potassium, free hydrochloric acid and the two enzymes, *pepsin* and *rennin*. The combination of pepsin and the acid is the ef-



On the left—stomach of the horse. A, end of the oesophagus; B, pyloric end, or beginning of the intestine. On the right—stomach of the sheep. O, oesophagus; P, rumen; R, reticulum; F, omasum; C, abomasum; I, commencement of the small intestine; 1, oesophagal groove; 2, opening between omasum and abomasum.

fective agent in the digestion. They are secreted by different gland cells in the stomach walls and the amount of hydrochloric acid secreted during 24 hours by a normal man, under ordinary conditions of diet, amounts to what would constitute a fatal dose of acid, if taken at one time in concentrated form. The main action of gastric juice is exerted on the proteins of the food, which under its influence, are gradually dissolved and converted into soluble products, known as proteoses and peptones. This enzyme, like the ptyalin of the saliva, is influenced by tem-

perature, maximum digestive action being manifested at about 38° C., the temperature of the body. Further, a certain degree of acidity is essential for procuring the highest degree of efficiency. Pepsin acts best in the presence of from 0.1 to 0.3 per cent of free hydrochloric acid. It is said that the gastric juice of the sheep has a low acidity, while that of the dog has the highest recorded among mammals.

Chemically, the results are the same in the stomachs of all farm animals, that is, the proteins are changed to the soluble forms known as proteoses and peptones. The utilization of coarse fodder by the horse is not as complete as in the ox for the reason that in the case of the former there is no preliminary remastication and trituration before the food material comes in contact with the gastric juice.

Another important function of gastric juice is that of curdling milk, due to the presence in the secretion of the peculiar enzyme known as rennin. This is present in the stomach of all mammals and it is the calf's active secretion, which is the source of commercial rennet used in cheese making. The purpose of this enzyme can only be conjectured. As the sole nutriment of the young, milk occupies a peculiar position as a food stuff, and being a liquid, its protein constituents might easily escape complete digestion were it to pass too hastily through the digestive tract. Experiments have shown this to be true of liquid foods. But when curdled by the rennin, the proteins of the milk in their clotted state, must remain for a longer time in the stomach, and their partial digestion by gastric juice made certain.

Among other factors in gastric digestion, the muscular movements of the stomach walls are to be emphasized, since we have here a mechanical aid to digestion of no small moment and likewise a means of accomplishing the onward movement of the stomach contents. From the stomach but little absorption of the soluble food materials takes place. It is in the intestine that both digestion and absorption are at their best.

Digestion in the intestine. When the food leaves the stomach it enters the small intestine. At this point it is only partially digested. The fats of the food have not as yet been changed, and undoubtedly a considerable proportion of the proteins and carbohydrates susceptible to solution is still to be acted upon. Immediately after passing from the stomach, the partially digested mass comes in contact with the pancreatic juice, the bile and intestinal juice, and the changes which began in the mouth and stomach, together with others which set in for the first time, proceed at a vigorous rate. The bile is secreted by the liver and stored in the small sac attached to that organ and called the "gall bladder" and from which it is brought to the intestine by a duct opening near the orifice leading out of the stomach. Bile is a reddish-yellow (in carnivorous animals) or green (in herbivora) liquid, with an alkaline reaction and bitter taste. It contains complex salts, which in conjunction with the fat splitting enzyme of the pancreatic juice, reduces the fats to an emulsion, a form in which they can be absorbed into the blood. When bile is prevented from entry into the intestine, the fat of the food largely passes out in the feces. Besides this important relation to fat digestion, the bile also acts in some degree as an antiseptic, preventing putrefaction in this part of the intestine.

The pancreatic juice is of strongly alkaline reaction due to its content of sodium carbonate, and is characterized by the presence of at least three distinct enzymes; these are trypsin, a protein digesting ferment; lipase, a fat splitting enzyme; and amyllopsin, a starch digesting enzyme. This juice comes from the pancreas and enters the intestine through a small duct, which in some animals is confluent with the bile duct. By the action of this juice, the acid chyme from the stomach is rapidly converted into an alkaline mass and the enzyme pepsin is quickly destroyed in the new environment. Trypsin, effective in alkaline media, now continues the protein digestion, splitting the proteoses and peptones, as well as unattacked proteins, into simpler structures. In this act it is aided by another enzyme, known as *erepsin*,

secreted by the mucus membrane of the intestine. These two enzymes are powerful agents and under their combined action the proteins are reduced, in part at least, to simple fragments, the amino-acids.

The fatty foods undergo little or no alteration until they reach the intestine. While in the stomach they become liquid from the heat of the body and the neutral fat is liberated from the cell structures by the action of the gastric juice. Most of the neutral fats must be decomposed into the fatty acids and glycerine, of which they are composed, before absorption into the blood can take place. Under the influence of the fat splitting enzyme of the pancreatic juice, lipase, and the bile salts, the neutral fats are partly decomposed, with formation of soaps. These soaps aid in the formation of an emulsion of the rest of the fats. Such an emulsion is really a suspension of the fat in a very finely divided condition. Soap, free acid and glycerine are then absorbed from the intestine and are found again combined in the lymph as neutral fat. In this way the fats are rendered available for the nourishment of the body.

The transformation of starch into maltose is again taken up by the amyllopsin of the pancreatic juice. The maltose is further exposed to an enzyme of the intestinal juice, termed *maltase*, and decomposed into the simple sugar, dextrose. Other carbohydrates, as the lactose of milk, and cane sugar, meet with special enzymes in the intestinal juice, capable of converting them into simple sugars, the final form in which the carbohydrates are absorbed.

No special enzymes fermenting the celluloses and pentosans, which constitute a large proportion of hays and straws, have as yet been prepared from the normal secretions of the intestinal tract. Possibly their partial solution is effected by bacterial ferments and other low forms of life. Such solution may have its beginning in the paunch, where active fermentations are in progress, and continue in the lower portions of the digestive tract.

Absorption of food. In the ways mentioned above, the proteins, fats and carbohydrates of the food are gradually digested. Throughout the length of the small intestine absorption proceeds rapidly; water, salts and the products of digestion pass out from the intestine into the circulating lymph and blood. There are two pathways by which absorbed material reaches the blood. In the intestinal wall are numerous projections, called villi. Imbedded in these structures are the minute branches of two systems of vessels. One set is the lacteals, belonging to the lymphatic system and the other the capillaries of the blood system. Materials passing into the lacteals reach the thoracic duct and by it, in a roundabout way, are carried into one of the main blood-vessels at the neck. As a general truth it may be stated that the fats are largely absorbed through this channel, and it is important to observe that when they reach the lacteals they are again in the form of neutral fats.

Materials absorbed by the capillaries of the blood system are carried directly to the liver through the portal vein, and there subjected to the action of that organ before they enter the general circulation. Most salts and the carbohydrates and proteins follow this course. In the liver the soluble sugars are converted into glycogen, the animal starch, and as such temporarily stored. The amount of sugar in the blood is a constant but small quantity and as this is required in the tissue, the glycogen is reconverted back into soluble sugar to maintain the supply in the blood.

The fragments of protein digestion, the proteoses, peptones and amino-acids, are not found as such in the blood or at least only in traces. Either in passing through the intestinal wall, or after reaching the liver, they are reconstructed into complex proteins before being cast loose into the circulatory system. These reconstructed proteins are the serum albumin, serum globulin and haemoglobin of the blood, which serve as sources of protein for the various body tissues. The processes of absorption

and blood regulation are wonderfully and delicately balanced and are by no means completely understood.

Feces. The portion of the food which has escaped solution and absorption, together with certain substances already absorbed but re-excreted by way of the intestines, constitute the feces. Epithelial cells from the intestinal walls, parts of the digestive juices, bile, bacterial cells, etc., will make up a large portion of the fecal matter.

Respiration. The nutrients, prepared by the various processes of solution and reconstruction in the intestines and intestinal wall, enter the blood on its return to the heart, coming into the venous circulation by way of the thoracic duct and liver (hepatic vein), as already described. By this route, the blood, laden with nutrients, passes to the right side of the heart. It is then carried to the lungs, by way of the right ventricle, to be returned to the left side of the heart, and from which it is pumped to all parts of the body. In the lungs the blood is supplied with oxygen. The purple of venous blood is changed to a scarlet, due to the absorption of oxygen by the haemoglobin, with the formation of oxy-haemoglobin, the important oxygen carrier of the blood. At the same time, a considerable quantity of carbon dioxide, most of which was in solution in the blood plasma, possibly as a bi-carbonate, is given up to the air within the lungs.

Inspired air contains about 21.0 per cent of oxygen and .03 per cent of carbon-dioxide, while expired air carries approximately 16.5 per cent of oxygen and 4.4 per cent of carbon-dioxide. Though the absorption of oxygen takes place in the lungs, it is not there that the processes of combining the oxygen with the carbon and hydrogen of the body tissues takes place. The blood, through the haemoglobin of the red-blood corpuscles, acts as a carrier of oxygen and the actual combustion of the products derived from the food occurs in the tissues themselves. The rate of combustion in the tissues is a variable one, dependent upon the amount of work the animal is doing and the temperature to

which it is exposed. And it is through this oxidation of the nutrients in the cells of the body that heat and mechanical work are produced.

Elimination. As has already been noted, the undigested residues of food, together with certain excretory products eliminated by way of the intestines, constitute the feces.

The products, which result from the metabolism of the body cells, or of the food consumed, are removed from the body by the lungs, the kidneys, the skin and the intestine. The carbohydrates and fats, which are oxidized in keeping up the animal heat or in furnishing energy, are broken down into carbon-dioxide and water and removed as such from the blood in the lungs, and to a smaller extent by the skin. Water and salts are removed by both intestine and kidney, while the perspiration may also serve to carry considerable quantities of these materials. The elimination of the products of protein degradation in the tissues is almost entirely by way of the kidneys. The larger part of the nitrogen is eliminated in the form of the simple body, urea. There are other forms of nitrogen occurring in the urine, such as uric acid, creatin, creatinin, ammonia, etc., but they constitute only a small proportion of the total nitrogen eliminated.

The sulphur of the protein molecule is also removed as sulphate through the kidney, while the phosphorus passes out of the body in the form of a phosphate by both the intestines and kidney; by far the larger proportion is removed through the intestine in the herbivora.

The quantity of nitrogen in the urine is taken as a measure of the amount of protein decomposition in the tissue. This may be only partly true. It is now believed that a considerable part of the nitrogen of ingested protein has not been built into body tissue, but is eliminated from the protein molecule as ammonia in the intestine, carried to the liver, and from there finally excreted through the kidney as urea. The carbonaceous part of the protein molecule from which this nitrogen has been removed

may now be used, through combustion, as a source of energy for the animal body.

When an animal is supplied with known quantities of food per day, it is possible, by collecting the feces and subjecting it to the same chemical analysis as was applied to the food, to determine how much of each constituent of the food has been digested by the animal. This applies particularly to carbohydrates, fats and proteins, although not strictly accurate for these. It does not apply to the mineral salts, as they are partly excreted through the intestine. But by such means the digestibility of feeds is measured and such results are of enormous value to the knowledge of animal feeding.

CHAPTER X

FEEDING STANDARDS

We have traced in the preceding chapter the processes of solution and the destination of the various nutrients of feeding materials. It will now be necessary to consider briefly the development of our knowledge leading to the establishment of feeding standards and the present status of such information. In 1810 Thaer, in Germany, formulated the first standard, publishing a table of hay equivalents, using meadow hay as the standard. It had little experimental foundation and soon fell into disuse. In 1859 Grouven published the first standard based upon the quantity of proximate constituents in feeding materials.

The work of Liebig, Boussingault, and others, with the new tools of a rapidly developing chemistry, was paving the way for standards based on chemical analysis. But the tables of Grouven did not meet the requirements, since they were based on the total, instead of the digestible nutrients.

In 1864 the feeding standards of Wolff, the eminent German scientist, first appeared. They are based upon the amounts of digestible protein, carbohydrates and fats, required by the various classes of farm animals. These standards have been published annually in the Mentzel-Lengerke calendar down to 1896; for the next ten years they were issued by Lehmann of the Berlin Agricultural High School, and since 1907 by Kellner, modified to a starch equivalent basis, to be described later. The Wolff standards have seen wide use by practical stockmen because of their simplicity and definiteness.

Co-efficient of digestibility. The nutrients of feeds are not wholly digestible. A part passes through the animal without having been dissolved by the digestive juices and thereby made available to the animal. The general method of measuring the digestibility of feeds has been to supply the animal with weighed

quantities of the feed, the composition of which has been determined by chemical analysis. During the experiment the solid excrement is collected and weighed and finally analyzed by the same methods as those previously applied to the feed. From the data thus collected the digestion co-efficients are calculated.

Example:

Digestion Experiment with Sheep (From Henry).

	Dry Matter	Protein	Crude fiber	Nitrogen free extract	Ether extract
	Grams	Grams	Grams	Grams	Grams
Fed 700 grams of hay (containing)	586.1	77.7	191.7	276.7	10.7
Excreted 610.6 grams dung (containing)	288.6	40.4	101.5	119.4	7.9
Digested	297.5	37.3	90.0	157.3	2.8
Per cent digested	50.8	48.0	47.1	56.8	26.2

From the example it will be seen that the digestion co-efficient is the proportion of each food constituent digested out of 100 parts by weight supplied. The figures secured are not absolutely accurate, due to intestinal secretions which become reckoned as undigested food. The co-efficients for proteins and fats suffer most in this regard. In experiments with oat straw the fecal nitrogen has been found to be more than that in the food, although the protein of the straw must have been digested to a considerable extent. Jordan states: "It is probably safe to affirm that at least 10 should be added to the co-efficients of digestibility of the protein of coarse fodders, as usually given in the tables that have been compiled." With fat co-efficients, an error is introduced through the secretion of bile into the intestine. This material contains products soluble in ether, the usual reagent used in determining the fat content of the feeding stuff. Consequently the undigested fat appears larger than it really is.

Conditions affecting digestibility. *Animals* differ in their power of digesting any given food or food constituent. For example, the ruminants, by their more thorough and repeated mastication, are better able to digest bulky fodder than are pigs and horses. This is illustrated in the following table taken from Jordan:—

Dry Substance Digested from Meadow Hay (Per Cent).

	Samples	Best	Medium	Poor
Sheep	42	67	61	55
Oxen	10	67	64	56
Horses	18	58	50	46

On the other hand the power of digesting bulky feeds by different classes of ruminants is very similar. Steers have been compared with sheep, and cows with goats, with no uniform difference in their digestive power for this class of feeds.

With the grains, the differences in digestibility with the various classes of farm animals are not greatly unlike. Comparative trials of oats with sheep and the horse gave nearly identical digestibility of the dry matter. With cows the result was similar. In other trials where beans were used the advantage was slightly with the ruminant. Swine digest the concentrated feeds as completely as do ruminants or the horse. Nor are they incapable of digesting vegetable fiber when presented in a favorable condition. Pigs fed on green oats and vetch digested 48.9 per cent of the fiber supplied. However, the digestive apparatus of the pig is not adapted for dealing successfully with bulky fodder.

So far as the influence of breed is concerned, this does not become a factor in the digestibility of feeds. A Jersey is as efficient in this capacity as a Holstein. Young animals appear to digest as efficiently as older ones of the same species. There are, very probably, differences in individuals, but the data so far collected do not definitely show this.

The influence of quantity of food on digestion is an unsettled point. The old experiments of Wolff indicated that a full ration was as completely digested as a scanty one. More recent ex-

periments in Europe, as well as in this country, give opposite results, indicating a higher rate of digestibility with smaller rations. The difference is not large and with appetite regulating the consumption, it is fair to assume that variations in food intake, incidental to normal feeding, will not markedly influence the power of digestion.

Influence of the quality of feed on digestibility. It is a popular belief that curing a fodder decreases its digestibility. This is probably true, especially where the drying has been conducted in a careless manner. The loss of leaves and the finer parts of the plant, and the washing out of soluble matter by rain are factors which will depress the digestibility of the fodder. For this reason, field cured corn fodder is considerably less digestible than silage coming from the same source. On the other hand, where the curing is done in such a manner as to exclude these losses, it is doubtful if it, in itself, has any appreciable effect upon digestibility.

The stage of growth of a fodder plant will influence its digestibility. That stage where there is a relatively high proportion of starch and sugar and a minimum of cellulose and lignins, will show a higher digestibility. As the grasses mature, the fiber increases; on the other hand, the corn plant furnishes a relatively higher proportion of digestible nutrients when the ears are full grown than before the ears have formed.

Influence of methods of preparation. Steaming, wetting and cooking the feed have received considerable attention. The general consensus of opinion of feeders, as well as the results of scientific experiments, do not indicate that these practices are of great advantage; beans, corn and bran are not better digested by the horse or ox when previously soaked in water. Barley, corn and pea meal have been found more nourishing for pigs when given dry than when previously cooked. Cooking certainly depresses the digestibility of the proteins. This has been experimentally demonstrated with steamed hays, silage, corn meal

and wheat bran. However, when cooking or steaming the feed renders it more palatable, and secures a larger consumption of material which otherwise would be wasted, the influence on digestibility is of less importance.

Grinding increases the digestibility of feeds. Mechanical division is an important factor in the rate and completeness of solution of material in the digestive tract. A single experiment with corn, fed to the horse, showed about 7 per cent increased digestibility from grinding, and with wheat, in one trial the increase was 10 per cent. With ruminants, the danger from imperfect mastication is less than with horses and swine. Whether it will pay to grind the grain will depend upon the cost of grinding and the loss of nutritive material from not grinding.

Influence of one feed on the digestibility of another. It is generally stated that the addition of a considerable quantity of protein to a ration of hay and straw consumed by a ruminant, is completely digested, without affecting the digestibility of the original feed. Pigs have been fed potatoes to which variable quantities of meat flour were added. The proteins of the meat were completely digested, while the proportion of potatoes digested remained unchanged.

It is also claimed that the addition of fat or oil to a basal ration of hay and straw was without influence on their digestibility.

On the contrary, Dietrich and Koenig state that if a *carbohydrate*, as starch or sugar, is added to the extent of more than 10 per cent of the dry substance of a basal ration, or if roots or potatoes, equivalent in dry matter to more than 15 per cent, are fed, a diminution of digestibility occurs. It is further stated that the depression of digestibility is reduced, when, accompanying the high starch intake, there is a corresponding increase in protein consumption. From these considerations, it is stated that highly nitrogenous feeds may be given with hay and straw without affecting their digestibility; but feeds rich in *carbohyd-*

rates, as potatoes and mangels, cannot be given in greater proportion than 15 per cent of the fodder (both calculated as dry food) without diminishing the digestibility of the latter.

Lindsey of the Massachusetts Station has, in part, confirmed the work of Dietrich and Koenig. He found that when Porto Rico molasses fed together with hay, constituted from 10 to 15 per cent of the total dry matter of the ration, little if any depression occurred. But with molasses constituting 20 per cent of the dry matter of the ration, a depression of 4.5 per cent was noted in the digestibility of the hay. He concluded that molasses and hay would not make a satisfactory combination for farm stock. A more suitable ration would consist of hay, together with one or more protein concentrates and molasses. Even in a ration of hay and gluten feed and in which molasses composed 20 per cent of the dry matter, there was a depression of 8 per cent in the digestibility of the hay and gluten.

The nutritive ratio. We have seen that the formulation of feeding standards must be based on a knowledge of the relative digestibility of the several nutrients contained in the feeding material. Such knowledge has been secured by many experimenters, working with various classes of farm animals, and has given us our tables of co-efficients of digestibility available in books on animal feeding. (See table in Appendix.)

It has been found in practice that the feed of an animal may be varied within fairly wide limits, provided the ratio of digestible protein to all other digestible organic matter is kept within certain limits. Protein has special and peculiar functions and less than a certain minimum would limit production by just the amount of the deficiency. In order to get this ratio it is necessary that some carbohydrate be taken as a standard for expressing the non-protein portion of the ration. Starch is the substance always chosen, and it becomes necessary, in order to express the fats and other carbohydrates in terms of starch, to obtain the equivalent in heat producing power of the other food constituents. This has been secured (1) by burning a weighed

portion of the various materials in a calorimeter (an instrument for measuring heat production), and (2) by direct experiments upon animals placed in a respiration calorimeter (an apparatus for measuring both gas and heat production), and fed with known weights of the various feeding-stuffs. As an average of several experiments it may be taken that one part of fat evolves as much heat as 2.4 parts of starch, sugar, cellulose or of protein. To express the non-protein, other than carbohydrates, in terms of starch, it is therefore necessary to multiply the quantity of digestible fat by 2.4 and add this product to the quantity of digestible carbohydrates present. The nutritive ratio thus becomes:

$$\frac{\text{digestible protein}}{\text{digestible carb.} + (\text{dig. fat} \times 2.4)}$$

The nutritive ratio of corn meal is obtained as follows:

$$\begin{array}{l} 100 \text{ lbs. contain } 7.9 \text{ lbs. digestible protein} \\ \phantom{100 \text{ lbs. contain }} 66.7 \text{ lbs. digestible carbohydrates} \\ \phantom{100 \text{ lbs. contain }} 4.3 \text{ lbs. digestible ether extract (fat)} \end{array}$$

$$\frac{7.9}{66.7 + (4.3 \times 2.4)} = \frac{7.9}{66.7 + 9.32} = \frac{7.9}{76.02} = \frac{1}{9.6}$$

The nutritive ratio for corn meal is therefore 1:9.6. This means that for every pound of digestible protein in corn meal there are 9.6 pounds of digestible carbohydrates and ether extract (fat) equivalent. The term "wide" ratio is used when there is a very large proportion of carbohydrates contained in a feed in proportion to the protein. Oat straw, with a nutritive ratio of 1:33.7, is an example of a very "wide" nutritive ratio. With corn the ratio is "medium," while with oil meal, with a ratio of 1:1.7 the expression "narrow" is used.

The Wolff-Lehman feeding standards. In 1864 Wolff proposed certain feeding standards, which have been largely used in framing rations. In order to eliminate the size of the animal, the proportion of the various feed constituents, to be supplied daily for 1000 pounds of body weight, are given. For illustration, a few standards are given here. (See full table in Appendix.)

For 1000 Pounds Live Weight Daily.

	Dry Sub- stance	Digestible			Nu- tritive Ratio
		Protein	Carbo- hydrates	Fat	
	Lbs.	Lbs.	Lbs.	Lbs.	
Cow, milk yield 22 lbs.....	29	2.5	13	0.5	1:5.7
Fattening steer, 1st period..	30	2.5	15	0.5	1:6.5
Horse, medium work.....	24	2.0	11	0.6	1:6.2

In formulating standards for ruminants it is better to start with two kinds of roughage, furnishing from 16 to 20 pounds of dry matter, and about 10 pounds of carbohydrates (nitrogen free-extract), and then add concentrates, which will on first calculation bring the total digestible protein somewhat under the standard. The additional requirements can then be easily computed. The term "fat" is identical with the "ether extract."

It is not necessary that a ration agree mathematically in all nutrients with the standard. To attempt to do this is to avoid the individual possibilities of the animal. The tables of digestion co-efficients and feeding standards are but averages and approximations. They are not to be followed blindly and absolutely, but if taken as guides, they can become extremely helpful. For example, the Wolff standards are quantities to be fed per thousand pounds of live weight. It is known that the food demands of an organism are not proportional to its size, but rather to its surface. This is because of a difference in demand on the heat producing function of a food. A small animal has a proportionately greater surface to its weight than a larger animal. Consequently it does not require the same proportional amount of digestible food to maintain a 1700 pound steer as one weighing 1000 pounds. For instance, Kuhn of the Mockern Station, found that a 1900 pound ox could be maintained on 0.7 pound of digestible protein and 6.6 pounds of digestible carbohydrates.

Other investigators have found that the Wolff allowances may be too high. Haecker of the Minnesota Station maintained a dry, barren cow of a 1000 pounds weight on 0.6 pound of digestible protein, 6 pounds of digestible carbohydrates, and 0.1 pound of digestible fat (ether extract).

Energy value of feeds. The function of food, as has already been pointed out, is not only to repair waste and promote growth and increase, but also to furnish heat and energy. For this reason, attempts have been made by several investigators to assess the relative value of feeds by a determination of their heat producing power. Heat units are expressed either in starch equivalents or calories. The German investigators, Kellner and Zuntz, have used starch as the basis for expression, while Armsby of this country is using the calorie. The calorie represents the quantity of heat required to raise the temperature of one gram of water from 0° to 1° C. A large Calorie, one thousand times larger than the small calorie, is usually employed for the expression of large quantities of heat and will be used here, generally. However, the new term, therm, which represents 1000 large Calories, is now in use by Armsby and is the quantity of heat required to raise the temperature of 1000 kilograms of water 1° C.

The value in large Calories of one gram of the several classes of nutrients, is given in the following table:

Wheat gluten.....	5.8	Cellulose	4.1
Animal muscle.....	5.7	Cane sugar.....	4.0
Starch.....	4.1	Animal fat.....	9.4

Available energy. The data in the above table is secured by complete combustion of the material in the calorimeter. Such does not obtain in the animal body. It should be remembered that only part is digested, and as only the digested portion furnishes available energy, the available fuel value of a ration must depend primarily upon the amount which is dissolved out of the digestive tract and passes into the blood. There is fuel waste in the solid excrement of the feces, in the incompletely burned gases

escaping from the alimentary canal, and in the unoxidized compounds of the urine. It has been estimated by Kuhn that the loss of energy in the gas, methane, which has its source in the fermentations of the digestive tract, amounts to over one-seventh of the energy of the digested crude fiber and carbohydrates. From this we see that the *available* energy of a ration represents the fuel value of the dry matter digested from it, minus the energy in the dry matter of the urine and that lost in excreted gases. Such data have been secured on a number of materials by the use of the respiration apparatus—an air tight compartment in which the animal could live and from which the gases could be removed for analysis. At the same time the urine and feces could also be collected for a complete chemical analysis and for a determination of the energy still contained in them.

Net available energy. We have seen that food is not applied to use until it reaches the blood. It must have work done upon it before it is in solution. The processes of mastication, of moving it along the digestive tract, and of bringing it into solution all require the expenditure of a certain amount of energy. Zuntz, working with a horse, has attempted to measure this. His method has been to determine by various devices, how much more oxygen is consumed during mastication and digestion than before or after these operations are accomplished. From this measure of oxygen consumption, he calculated the following heat units, representing the energy used in chewing certain feeds:

	Cal.
1 pound corn. (454 grams).....	6.3
1 pound oats.....	21.0
1 pound hay.....	76.0

✓ This is an important finding. Zuntz calculates that in general the coarse feeds have 20 per cent less net energy value than the grains and that the work of mastication and digestion combined is about 48 per cent of the energy value of the digested material from hay and 19.7 per cent of that from oats. We must remember, however, that the wastefulness of fibrous foods shown in

these determinations on the horse are not true to an equal extent in the case of ruminants. In the latter the fiber is softened in the paunch and its digestion has begun before it reaches the intestines.

Net available energy then, is the available energy minus the energy of digestion and preparation of the food for use. This internal work furnishes heat, and provided it is not in excess of the heat requirement of the animal, should not be regarded as waste. The waste of heat has begun when that produced by the work of digestion exceeds the animal requirement. But if it is produced in the digestive tract and not in the tissues of the animal, it cannot appear as useful work.

We learn from this that it is not the total chemical energy in a feeding stuff which measures its value to the body, but that which remains after deducting the energy losses in the unburned material of the excreta, the energy expended in digesting the real fuel materials from the food, and in addition, the energy used in transforming them into substances which the body can use or store up. This gives us what Kellner calls the *productive value* of feeds, and is identical in meaning with the term *net available energy* of feeds.

Productive value of feeds. From elaborate experiments with the respiration chamber and mature oxen Kellner has determined the productive value of certain feeds. For this purpose he chose rather lean oxen, giving them a fixed moderate ration which resulted in a small increase in weight. He then added to the ration the feed to be experimented with, and determined the amount of increase produced. This was not done by weighing the animal, but by determining the amount of nitrogen and carbon retained by the animal. The protein tissue stored, was calculated from the nitrogen retained and the fat from the carbon left after deducting the carbon required to build the increase in protein. Kellner's results are shown in the following table.

The available energy of these feeds had already been determined and is given in the first column. In the second column appears the percentage of loss in the process of digestion and

assimilation and production of tissue. The last two columns express the energy value of the increase and the comparative productive value of the different materials, with starch as a unit. We see from this that 56.3 per cent of the digested fat (peanut oil) was stored, and 44.7 per cent of the digested protein (wheat gluten), while but 17.8 per cent of the digested wheat straw was available for useful energy or increase. This gives us a scientific explanation of the fact that coarse feeds are not adapted to rapid production.

From such data Kellner concludes that 1 pound of digested

*Heat Values of Digested Feeds and of the Increase Obtained
in a Fattening Ox.*

	Heat value to the ox of 1 gram of digested substance	Loss of energy in productive processes	Heat value of increase obtained	Comparative productive value. Starch 100
	Cals.	Per cent	Cals.	
Starch	3.7	41.1	2.2	100
Molasses	3.6	36.4	2.3	104
Straw pulp	3.6	36.9	2.3	104
Wheat gluten	4.7	55.3	2.1	101
Peanut oil	8.8	43.7	4.9	224
Meadow hay	3.6	58.5	1.5	68
Oat straw	3.7	62.4	1.4	64
Wheat straw	3.3	82.2	1.6	27

starch may yield a maximum of 0.23 pound of body fat, the rest being consumed in the transformation processes. Taking 1 pound of digestible starch as his standard, he has formulated the relative values for the digestible nutrients in feeding stuffs, based on the amount of body fat the several pure nutrients would form if fed to the ox.

Kellner's starch values. These are the values of the nutrients of feeds expressed with starch as a unit of energy. From the quantities of digestible nutrients in 1000 pounds of ordinary feeding material, the relative value of feeds for maintenance and

production in terms of starch have been calculated by Kellner. No extended table will be given here. However, to make this clear the digestible nutrients in a few common feeding materials are brought together in the following table. This table includes the amides, which are not, in American tables as a rule, distinctly separated, but included under the term "crude protein" ($N \times 6.25$).

Pounds of Digestible Matter in 1000 Pounds of Various Feeds.

	Total organic matter	Nitrogenous Substances		Fat	Carb.	Fiber
		Protein	Amides			
Corn	786	73	6	44	651	12
Oats	600	81	7	45	441	26
Barley	715	70	4	19	607	15
Clover hay	440	47	25	13	269	151
Oat straw	381	7	5	7	163	199
Wheat straw	351		4	4	150	193

From these data the *maintenance* value in terms of starch is made by the simple calculation:—Protein $\times 1.25^1$ + Amides $\times 0.6$ + Fat $\times 2.3$ + Carb. + Fiber.

From this we see that the feeds for *maintenance* are valued at the full heat value of the *digestible* constituents. The heat which is the final outcome of the mechanical labor employed in digestion, can serve for warming the animal. But when the *productive* value is considered, it has been found that if we take only the *digestible* fat, protein, and carbohydrates of the ration, and give to each the energy value found for it in Kellner's production experiments, the sum of these will approximate the values actually obtained in the experiments tried. Consequently the *productive value* in terms of starch = Fat $\times 2.3$ + Protein + Carb.

¹The factors 1.25, 0.6, and 2.3 are those in use in Europe for converting the food constituents to an energy basis equivalent to starch. It should be observed that generally the factor 2.4 for fat is the one used.

In the following table are assembled a few examples of the starch equivalents of feeds for both maintenance and production, as formulated by Kellner.

Comparative Value of Ordinary Feeds for Oxen and Sheep.

	<i>For Maintenance</i>		<i>For Production</i>	
	Value of 1000 lbs. as starch	Quantities equivalent to 1 lb. of starch	Value of 1000 lbs. as starch	Quantities equivalent to 1 lb. of starch
Corn.....	859	1.16	825	1.21
Oats.....	676	1.48	626	1.60
Barley.....	755	1.32	721	1.39
Clover hay.....	459	2.18	319	3.13
Oat straw.....	412	2.43	207	4.83
Wheat straw.....	357	2.80	96	10.41

Kellner admits that our knowledge of the actual productive value of feeds is still very incomplete. Such values have been determined by actual experiments in only a few cases and then only for the mature fattening ox. It serves, however, to illustrate the trend of experimentation and the serious and laborious attempts being made to place the nutritive value of feeding stuffs on a scientific experimental basis. It appears from the above table that approximately 2 pounds of oat or wheat straw may replace 1 pound of corn, if the ox or sheep is merely on a maintenance diet, but that 1 pound of corn will have as great an effect as 4 pounds of oat straw or 10 pounds of wheat straw when the animal must grow or fatten.

Kellner's feeding standards. The first table on the following page is a brief summary of these standards.

Armsby's feeding standards. As an outgrowth of the work of Kellner and continued work with the respiration calorimeter, Armsby has begun to formulate feeding standards, giving the net productive energy of feeding stuffs. These are expressed in

Standard Rations for 1000 Lbs. of Farm Animals.

	Dry matter	Digestible Nutrients	
		Proteins	Starch value
	Lbs.	Lbs.	Lbs.
Maintenance of mature steers.....	15-21	0.6	6.0
Fattening steers.....	24-32	1.5-1.7	12.5-14.5
Milch cow giving 20 lbs. milk daily...	25-29	1.6-1.9	9.8-11.2
Milch cow giving 30 lbs. milk daily...	27-33	2.2-2.5	11.8-13.9
Horse at light work.....	18-25	1.0	9.2
Horse at heavy work.....	23-29	2.0	15.0
Fattening swine 1st period.....	33-37	3.0	27.5
Fattening swine 2nd period.....	28-33	2.8	26.1
Fattening swine 3rd period.....	24-28	2.0	19.8

therms, and for illustration several examples are brought together in the following table. The complete table will be found in the appendix.

Dry Matter, Digestible Protein and Energy Value in 100 Lbs.

Feeding stuff	Total dry matter	Digestible protein	Energy value
	Lbs.	Lbs.	Therms
Green alfalfa.....	28.2	2.50	12.45
Dry alfalfa.....	91.6	6.93	34.41
Oat straw.....	90.8	1.09	21.21
Corn meal.....	89.1	6.79	88.84
Wheat bran.....	88.1	10.21	48.23

The table is supposed to represent, with a fair degree of accuracy, the digestible protein and the net energy which the various feeding stuffs will supply. They express what is available to the animal for growth, fattening, work or milk production, after deducting that used in the work of mastication and assimilation. The digestible protein in the table is true protein and does not include the so-called "amides" of the "crude protein."

Standards for maintenance. The following table shows the amount of digestible protein and net energy required per head for the maintenance of cattle, sheep and horses of different weights. No figures for swine are available.

Armsby's Maintenance Standards for Horses, Cattle and Sheep.

Live weight	<i>Horses</i>		<i>Cattle</i>		Live weight	<i>Sheep</i>	
	Digestible protein	Energy value	Digestible protein	Energy value		Digestible protein	Energy value
Lbs.	Lbs.	Therms	Lbs.	Therms	Lbs.	Lbs.	Therms
150	.15	1.70	.30	2.00	20	.02	.30
250	.20	2.40	.40	2.80	40	.05	.54
500	.30	3.80	.60	4.40	60	.07	.71
750	.40	4.95	.80	5.80	80	.09	.87
1000	.50	6.00	1.00	7.00	100	.10	1.00
1250	.60	7.00	1.20	8.15	120	.11	1.13
1500	.65	7.90	1.30	9.20	140	.13	1.25

From the table one sees that a colt of 500 lbs. weight will require for daily support 0.3 lb. of digestible protein and 3.8 therms, while when it has trebled its weight the requirements are 0.65 lb. of digestible protein and 7.9 therms. In other words the requirements have not increased in proportion to the gain in weight.

Standards for growing animals. The following table gives the digestible protein and energy required for growing cattle and sheep, as set forth by Armsby. No data for horses and swine are available. The table includes the maintenance requirement.

The table shows that a six months old calf, weighing 425 pounds requires 1.3 pounds of digestible protein and 6 therms of energy value, which includes the 1.3 pounds of protein. Where the calf has grown to weigh 1100 pounds, or more than doubled its weight, it requires 0.35 pound more protein and 2 more therms. This relative lessening in feed required is due to the fact that a larger

animal requires relatively less for maintenance, and to the additional fact that the rate of growth has greatly decreased. Armsby allows 1.75 pounds of digestible protein for a steer weighing 1000 pounds, while but 1.65 is required when the same steer reaches 1100 pounds. This is due to the lessened increase in muscular tissue and consequently decreased demand for protein food, as compared with the earlier stages of life. It should be noted that in comparing maintenance and growing requirements, the larger part of all the food consumed is used for body support, and that additional requirements for growth are mainly in protein, rather than therm requirements.

Armsby's Standards for Growing Cattle and Sheep.

Age	Cattle			Sheep		
	Live weight	Digestible protein	Energy value	Live weight	Digestible protein	Energy value
Months	Lbs.	Lbs.	Therms	Lbs.	Lbs.	Therms
3.....	275	1.10	5.0			
6.....	425	1.30	6.0	70	.30	1.30
9.....				90	.25	1.40
12.....	650	1.65	7.0	110	.23	1.40
15.....				130	.23	1.50
18.....	850	1.70	7.5	145	.22	1.60
24.....	1000	1.75	8.0			
30.....	1100	1.65	8.0			

Standards for milch cows and fattening steers. In addition to the foregoing standards, Armsby recommends the following:

1. For milk production add to the maintenance standard 0.05 pound of digestible protein and 0.3 therm for each pound of average milk containing 13 per cent of total solids and 4 per cent of fat.

2. For fairly mature fattening cattle add 3.5 therms to the maintenance standard for each pound of gain in live weight.

Armsby does not provide additional protein to the maintenance standard for fattening steers, holding that if the proper allow-

ance of therms is provided in addition to the maintenance ration, no additional protein is required for fattening purposes. On the other hand, for milk production the standard provides additional protein. This must be done because of the protein content of the milk itself and the additional factor of protein supply for the developing foetus.

3. Armsby recommends that a 1000 pound ruminant should be given from 20 to 30 pounds of dry matter per day, while for the horse smaller amounts can be used.

Standard for the working animal. The horse is the only animal to be considered here. What applies to the horse may also be used for the mule. As a general average, Kellner recommends the following ration for a 1000 pound horse, the amounts stated including the maintenance requirement:—

Requirements of the Working Horse.

	Digestible protein	Energy value
	Lbs.	Therms
For light work.....	1.0	9.80
For medium work.....	1.4	12.40
For heavy work.....	2.0	16.00

Future of standards. The feeding standards being developed at the present time are in a formative stage, and necessarily incomplete. No standard should be used as an exact mathematical expression of the animal's needs. In fact it cannot be done, because we are not in a position to know the exact requirements of the individual animal; again, feeding stuffs of the same name show a considerable range in composition. Further, probably the most important factor in limiting the adoption of a feeding standard as a final recipe in feeding, is the difference in nutritive value and physiological action of the nutrients from various sources. One species of farm animal may do better on the nutrients from one specific source, as compared with those derived

from another. In addition, the relative amounts and kinds of ash must be considered. The value of wheat bran does not reside wholly in its protein content, but partly in its laxative properties, which are due to a specific constituent, known as phytin. The superior value of legume hays must be attributed, in part, to their high lime content. This is particularly true when used for growing animals and milch cows. All these are factors to be reckoned with, but until they are completely worked out and catalogued, the student will still find the standards of Wolff or Armsby helpful in formulating rations.

CHAPTER XI

FOOD REQUIREMENTS OF ANIMALS.

The young growing animal. The distinct and characteristic feature of the growth of young animals is the rapid formation of soft tissue and bone. For this purpose there must be an abundant supply of protein and suitable ash.

This is true for all young domestic animals. The daily increase in live weight of a well nourished calf is very considerable and may be as large as that of a well-fed, mature steer. It may amount to 2 pounds per day; and much less than this would be regarded as unsatisfactory. Lawes and Gilbert analyzed the entire body of a fat calf with the following results:—

	Per cent
Water.....	64.6
Ash.....	4.8
Protein	16.5
Fat	14.1

Based on this analysis the daily increase of 2 pounds live weight in a growing calf would mean a storage of about 0.33 lb. of protein and 0.28 lb. of actual fat, or a total increase of 0.61 lb. of dry body material. This may be equal to one-fifth or more of the total dry substance of the ration. European investigations with calves have shown that one pound of milk solids, practically all digestible, produced one pound of increase in live weight. Because of the water content of this increase, the actual dry matter is equal to about one-third of a pound. Further, these studies showed that 70 per cent of the protein of the food was retained in the bodies of the calves and 72 per cent of the phosphoric acid and 97 per cent of the lime held for skeleton and tissue expansion. On an assumed consumption of 10 pounds of average milk daily, this would mean a retention of 6.4 grams (approximately one-fifth of an ounce) of phosphoric acid and 8.7 grams of lime.

In this country, experiments with young lambs fed cow's milk showed a gain in live weight of one pound for every 5.8 pounds of milk consumed. If the milk contained 13 per cent of dry matter, then 0.75 pound of milk solids produced 1 pound of increase. This is a high food efficiency and practically ten times that shown with animals somewhat mature. This serves to illustrate the rapid increase in tissue during the early periods of growth.

The kind of food most appropriate to the wants of the young animal is revealed by the composition of milk. The first milk secreted by the mother (colostrum) is very rich in protein, often containing as high as 15 per cent. This gradually changes after parturition and after a lapse of 8 to 10 days the composition of the secretion becomes normal. Below is given the composition of colostrum and the normal milk of our common farm animals.

Percentage Composition of Colostrum Milk.

	Water	Protein	Fat	Sugar	Ash	Nu- tritive ratio
Ewe	66.4	16.6	10.8	5.0	1.2	1:1.8
Sow	70.1	15.6	9.5	3.8	0.9	1:1.6
Cow	74.7	17.6	3.6	2.6	1.5	1:0.6

Percentage Composition of Milk.

Ewe	80.8	4.9	6.9	4.9	.84	1:3.1
Sow	84.6	5.2	4.8	3.2	.80	1:2.2
Cow	87.0	3.5	3.9	4.8	.70	1:3.7
Mare	90.8	2.0	1.2	5.6	.40	1:3.9

The solid matter of milk has a high feeding value, because of its complete utilization by the animal. It also supplies an abundant amount of ash material for skeleton and tissue formation. That each species has provided for the young a milk of such pro-

tein and ash content as will meet the rate of development characteristic for that species is seen in the following table:—

	<i>Protein</i>	<i>Ash</i>	<i>Days required to double weight</i>
Ewe.....	4.9 per cent	0.84 per cent	15
Sow	5.2 “ “	0.80 “ “	14
Cow.....	3.5 “ “	0.70 “ “	47
Mare.....	2.0 “ “	0.40 “ “	60
Human.....	1.6 “ “	0.20 “ “	180

This is a very suggestive relation of the protein and ash content of milk to the rate of growth and serves to illustrate the necessity of maintaining a liberal supply of these materials in easily available form for the growing young. It is also necessary to remember that approximately 50 per cent of the ash of milk is made up of the bone-forming constituents, lime and phosphoric acid. This emphasizes the desirability of maintaining the supply of these ash constituents in the feed of the animal as the mother's milk is withdrawn and other feeds substituted.

Supply of ash material necessary. Probably no class of farm animals is exposed to as much danger in this regard as the pig. Abundant supplies of lime, in particular, are contained in the hays and leafy parts of plants, but these, normally, do not form a part of the ration of this species of farm animals. The grains are low in lime; and even wheat bran, so often accredited with abundant bone forming materials, is relatively low in lime. It contains an abundant supply of phosphorus, and in so far as the supply of this element is concerned, normal rations for all classes of farm animals, of which the grains and particularly wheat bran form a part, will generally supply a sufficient quantity. In furnishing an abundant natural supply of lime to the growing animal, recourse may be had to the legume hays for ruminants or the ground meal from alfalfa or clover hay for the young pig.

The meadow hays are also rich in lime, but do not contain as

much as the legume hays. The beneficial use of wood ashes, as a supplement to corn in the ration of pigs, probably lies, in part at least, in its high lime content. The use of artificial sources of lime for growing animals of all classes, where the natural sources are not available, is highly justifiable. Probably lime as a phosphate serves this purpose best, and either what is called precipitated calcium phosphate or the crude, finely ground phosphate known as "floats" can be used to advantage. About $\frac{1}{4}$ to $\frac{1}{2}$ of an ounce per 100 pounds of live weight during the rapidly growing periods should serve the purpose of building a strong skeleton.



The effect of improperly balanced rations on growing animals. The ration fed these pigs was too low in phosphorus.

No attempt is made here to give directions for feeding animals; this must be sought for in texts wholly devoted to that subject. Only a few of the more fundamental principles are discussed.

Dangers from too rich milk. In recognizing the mother's milk as supplying the nutrients in the best forms and proportions, it is necessary to add that milks very rich in fat have been found to cause intestinal disturbances and impaired nutrition. This is not only true of cow's milk fed the calf, but also true when that milk is fed to pigs or to the human infant.

The following explanation for this harmful effect of excess of fat in the food has been offered:—The general capacity of an organism for the absorption of fat is strictly confined within narrow limits and consequently an excessive supply is not absorbed,

but remains in the intestine. There it is converted into soaps, composed of part of the fat and an alkali, and as such eliminated from the body in the excreta. This excretion of soap entails to the body a heavy loss of alkaline bases, which when continued for some time results in disturbed nutrition. On an exclusive milk diet containing 3.5 per cent of fat the supply of alkaline bases is only sufficient for normal development and the production of fat-rich milk in cows is not attended by a corresponding increase in the ash forming materials. Rich milk is the result of breeding by man and is not a condition original to the milk of the cow.

Another important fact to bear in mind is that the capacity to digest the starchy grains and similar substances is somewhat undeveloped in the very young animal and that the ferments necessary for this purpose are probably not yet very abundant. For this reason the first substitute for milk should not consist too largely of cereal grains, or concoctions of insoluble, starchy materials. Bulky, fibrous food is likewise unsuitable for the young animal. The digestive tract of calves and colts must gradually expand before the coarse hays can form a large part of their ration.

Influence of food. In experiments on the influence of food upon the development of the animal body, some interesting results have been recorded. Sanborn and Henry fed to swine rations varying considerably in the protein and ash supply. Comparisons of middlings and blood against corn meal alone, or shorts and bran against potatoes, tallow and corn meal, showed considerable differences in the development of the animal. Those fed high nitrogenous rations contained more blood than the others, while such organs as the kidney and liver were larger in proportion to the weight of the body, the bones stronger, and the proportion of muscle greater. These were extreme rations, and not likely to occur in practice, but the experiment serves the purpose of emphasizing the necessity of an abundant supply of protein and ash material for the growing young. Swine fed on corn and gluten feed, against corn, gluten feed and "floats" have shown marked

differences in the skeleton development. In this experiment the proteins were abundantly supplied in both rations, but only in the second was there a liberal supply of lime and phosphoric acid. Where such a supply was maintained the skeletons were large and strong.

Jordan fed two lots of steers from calf-hood on rations widely different in their nutritive ratio. The one lot received for grain, oil meal, wheat bran and corn meal, and the other lot corn meal, with a minimum proportion of wheat bran. A nutritive ratio of 1:5.2 and 1:9.7 was maintained. At the end of 17 months and 27 months, one animal from each lot was killed and the entire body, exclusive of hide, analyzed. There was no material difference in the composition of the animals. "The amount of growth was at first more rapid with the more nitrogenous ration, but the kind of growth appeared to have been controlled by the somewhat fixed constitutional habits of the breed." (Jordan.)

It is sometimes claimed by practical men that feeds rich in bone-forming materials should be withheld from the pregnant mother; that such feeds are conducive to large boned offspring, making it difficult for the young to be born. Little data on this question are available, but from some experiments on swine at the Wisconsin Station, there is no evidence that excessive supplies of bone-forming materials influence the size or the ash content of the skeleton of the newly born. It appears that the power to maintain a constant composition for the foetus, independent of wide variations in food supply, lies inherent in the mother.

The adult animal and food for maintenance. The food of an adult animal, neither gaining nor losing in weight, is used for renewal of waste tissue, the growth of hair, horn and wool, and for the production of heat and mechanical work. The work performed consists in the muscular movements involved in chewing and moving the food along the intestinal tract; muscular movements of the heart in pumping the blood; respiration and the metabolic activity of the cells in causing the chemical transformations of the nutrients. This is internal work. It has been cal-

culated that the power exerted daily by the heart of a man 150 lbs. in weight, would raise 1 ton to a height of 242 feet. Then in addition, there is always some work done in moving the body from place to place. A horse of 1100 pounds weight, walking 20 miles on level ground, and without a load, will do work equivalent to raising 2328 tons 1 foot. The internal work finally appears largely as heat, while in the external movements of the body, probably 70 per cent of the total energy developed in the muscles appears as heat.

The smaller the animal the greater the loss of heat per unit of weight, and consequently the more liberal must be the supply of food. This is because small bodies have in proportion to their weight, a much greater surface. Thus, heat is lost by radiation from the surface of the body and in evaporating the water exhaled through the lungs and skin.

In the following table the heat production in resting animals is given:—

Heat Production in Resting Animals.

	Weight in pounds	Calories produced	
		Per pound	Per sq. mm. surface
Horse	970.0	24.8	948
Pig	281.0	42.0	1078
Dog	33.0	103.0	1039
Goose	7.7	146.7	943
Mouse	0.03	466.0	917

This shows that animals will produce heat in proportion to their surface; it is interesting to note that in the standard rations for animals, the quantity of food increases at nearly the same ratio as the surface increases. For example, while the oxen in growing from a weight of 165 to 935 pounds increases in weight 5.7 times, the surface of the animal increases but 3.2 times and the food required, 3.5 times.

It is essential that the maintenance ration should supply enough protein to replace the daily waste of the nitrogenous tissue. Only a small amount is necessarily destroyed by the resting animal; but there is a constant waste, and unless this is replaced the animal will die of starvation. It is plain then that the demands upon food for maintenance purposes are mainly for the production of muscular energy and heat. Armsby found that a supply of 0.6 lb. of digestible protein per day was sufficient for the permanent maintenance of a 1000 pound ox, receiving a ration with a nutritive ratio of 1:11.

The thorough studies of Zuntz on the horse have shown that a 1000 pound animal can be maintained on 6.4 pounds of available nutrients, provided the total ration does not contain more than three pounds of crude fiber. This means that the nutrients must come from hay and grain. Grandeau places the maintenance requirement for the same weight of animal at 7 to 7.8 pounds of digestible organic matter, including 0.45 pound of digestible protein.

There are few experiments with sheep, but according to German experiments, 11.8 pounds of digestible organic matter, including 1.0 pound of digestible protein, per 1000 pounds live weight are required to maintain proper conditions. Its continued production of wool, higher temperature and smaller size make the requirements for this animal somewhat more liberal than with the horse or ox.

It is clear then that 90 per cent or more of a maintenance ration may consist of carbohydrates or materials used solely for fuel. This makes it easy to supply this ration from the home grown products. The quantity of available nutrients consumed is small and may largely be made up of coarse material, such as corn fodder and hay. Again, the low protein requirement and the possibility of a wide nutritive ratio, characteristic of home grown products, makes its selection easy.

Requirements for labor. As the horse is practically the only animal used in this country for draft and road purposes, it will

be considered alone in this connection. The source of the energy evolved during labor and appearing as extra work and heat must come from the oxidation of food. If work is to be performed and at the same time body weight remain constant, the quantity of food must be increased.

It was supposed at one time that muscular effort was produced by the oxidation of the nitrogenous constituents of the muscle, and that a ration very rich in protein was necessary, if hard work was to be maintained. This idea is now known to be erroneous. Men have climbed mountains and measured the excretion of urea (the principal nitrogenous constituent of the urine) during such severe exercise. There was no important increase in its production under such conditions. Increased work increases the excretion of carbon dioxide but not of nitrogen. In other words, the carbohydrates and fats are largely the fuel materials that furnish energy for mechanical purposes.

Zuntz has determined the quantity of food which a horse needs in order to perform work under varying conditions. "A horse weighing with harness 1144 pounds, will require 1.33 pounds of available food to walk 10 miles at $2\frac{1}{2}$ miles per hour; 1.69 pounds when walking the same distance at a speed of $3\frac{1}{3}$ miles per hour; and 2.53 pounds when trotting the same distance at 7 miles an hour." This is important knowledge on the influence of speed upon the food requirement in a unit of time.

The pace of the animal is another important factor. Grandean and Leclerc kept a horse in good condition, walking $12\frac{1}{2}$ miles a day with a daily ration of 19.4 pounds of hay, but when the same distance was done trotting, 24 pounds was insufficient. A horse walking the above distance and hauling a load (equivalent in additional work to 1943 foot-tons) was maintained by a ration of 26.4 pounds of hay; but when the same work was done trotting, a daily ration of 32.6 pounds of hay, which was all it would eat, was insufficient to maintain weight. Trotting or galloping involves additional internal work; the animal also lifts its own weight at each step, which only appears as heat as it falls back

again. Consequently horses of different "action" will require unlike amounts of food to accomplish the same task.

When a horse exerts itself to the utmost the consumption of oxygen rises rapidly and the food consumed per unit of work may be nearly twice as much as with ordinary draft. A slow pace, consistent with conditions involved, will be economical of food consumption per unit of work performed.

Zuntz found that the requirements for a horse, plowing 8 hours a day, were 14.03 pounds of digestible nutrients. This is somewhat less than the requirement found in the German standards of Wolff and Lehmann. According to these formulas, a 1000 pound horse requires 11.4 pounds of digestible food daily for moderate work, 13.6 pounds for average work, and 16.6 pounds for heavy work. These standards also call for a nutritive ratio of 1:7 to 1:6, dependent upon the severity of the labor. On the other hand, Lavalard, recommends that 1.15 pounds of digestible protein daily is sufficient for ordinary labor, and 1.35 pounds when the labor is severe. This is a nutritive ratio not far from 1:10. From what has been said on the source of muscular force, it is probable that the nutritive ratio recommended by the German standard is narrower than need be. Horses working on the sugar plantations of the Fiji islands receive 15 pounds of molasses per day and a nutritive ratio of 1:11.8. However, a fairly good proportion of protein, for its peculiar and characteristic dynamic effect, appears advisable.

It is the opinion of Jordan that "rations properly compounded from ordinary farm products, such as silage, roots, meadow hay, legume hays and the cereal grains, will generally contain protein in sufficient proportion and will seldom need reinforcing with the commercial nitrogenous feeding stuffs."

If a horse at severe labor requires 16.6 pounds of digestible nutrients, it is manifest that this could not be obtained from the coarse fodders. Concentrated feeds must be used. Ten pounds of hay is all a work horse should consume in one day. We have seen that the productive value of the coarse feeds is not as large

as the grains, and consequently cannot be expected to furnish available energy for severe labor in sufficient quantity, compatible with the storage capacity of the digestive apparatus of the horse.

There has been a strongly established opinion that oats are pre-eminently the horse feed and must form a generous proportion of the grain ration; that they give life and nerve to the animal. At one time the discovery of a special compound, "Avenin," resident in the oat kernel and endowed with these stimulating properties, was announced. This is now disproved and it is becoming more and more evident that other grains can be substituted for oats with no impairment to the animal's well being.

Fattening requirements. To increase body weight it is necessary that the food supply be in excess of that required for maintenance and for the production of heat and work. When such an excess is given, the protein and ash are in part converted into new tissue, and the fats, carbohydrates and possibly proteins, stored up in the form of fat. Feeding a young animal an excess will promote the further development of bone and muscle, while in the case of the mature animal, the increase will come almost wholly from the deposition of fat in the tissues. In both instances fat forms the largest proportion of the increase. This is shown in the following figures:—

Composition of Increase When Steers are Fattening.

	Water	Ash	Protein	Fat
	Per cent	Per cent	Per cent	Per cent
Oxen, fattening very young	32-37	2.25	10	50-55
Matured animals, final period . .	25-30	1.5	7-8	60-65

These figures serve to illustrate how the food is used, and that the increase is largely fat formation. A satisfactory gain of 2 pounds per day would then mean a storage of 1.3 to 1.5 pounds of dry substance, of which about 0.2 pound is protein. From the fact that carbohydrates can serve as sources of fat, it is evident that the non-protein part of a ration may be the chief source of the increase laid on by a fattening animal. The protein require-

ment for the constructive work is apparently small. It would appear from this that the nutrients serving mainly for fat formation need not come from proteins in the ration, but rather from the fats and carbohydrates. Further, from a theoretical point of view, this would lead us to the conclusion, that for fairly mature fattening animals the nutritive ratio may be wider than that recommended in the German standards. These standards call for a ratio of from 1:5 to 1:7 in the various classes of fattening farm animals.

Kellner, from experiments on oxen, declares that a fattening ration may vary in its nutritive ratio from 1:4 to 1:10 without affecting the amount of increase per unit of digestible matter, provided the nutrients supplied above maintenance come from easily digestible feeding stuffs. Armsby, in his standards for fattening steers, provides no additional protein above maintenance, only allowing additional therms, which simply represent material for fuel and fat formation. Certain practical feeding experiments show that wide rations have been as effective as the narrower ones. On the other hand there are experiments of this class which show more rapid gains when a larger proportion of protein was furnished. Possibly these are to be explained on the basis of increased palatability and variety of nutrients, thereby securing an increased consumption. The proportion of protein was probably a minor factor. When the nutrients supplied secure palatability, ease of digestion and bowel regulation, it is probable that they need not be of very highly nitrogenous character.

Facts bearing on this point are disclosed in the pig feeding experiments at the Rothamsted Station and are appended in the following table.

The figures in the last column are not the nutritive ratios, which apply to digestible matter, but simply the ratios of nitrogenous to non-nitrogenous matter. The true nutritive ratio would be considerably wider. The results clearly show that 100 pounds of increase were produced with practically the same consumption

of organic matter, notwithstanding the great variations in the quantity of protein supplied.

In the case of sheep, the fattening process is not greatly unlike that of steers, the increase being, however, somewhat richer in fat.

It is probable then, that for fattening animals a nutritive ratio somewhat under that recommended by the Wolff standards is not inconsistent with successful feeding. However, if the animal is still growing, then it is apparent that a wide ratio is not con-

Fattening Pigs on Food Rich and Poor in Protein.

Food Supplied	Consumed to produce 100 lbs. of gain			Ratio of protein to non-protein
	Protein substance	Non-protein substance	Total organic matter	
	Lbs.	Lbs.	Lbs.	
Beans and lentil meal.....	137	291	428	1:2.1
Beans, lentil and corn.....	113	297	410	1:2.6
Starch, sugar, lentil, bran....	81	329	410	1:4.1
Starch, lentil, bran.....	80	340	420	1:4.2
Corn, bean, lentil, bran.....	72	338	410	1:4.7
Corn, bean and lentil.....	72	366	438	1:5.1
Corn and bran.....	58	362	420	1:6.3

ducive to best results. From this it follows that the home grown fodders and grains can furnish the main sources of the nutrients required for fattening purposes. It must always be kept in mind, however, that mere mathematical formulas should not form the basis for calculating supplies for the living organism. The feeder recognizes the value of a little oil meal and middlings in keeping the animal in "condition" for best results, but it is not to be assumed that their entire value lies in their protein content. The economy of a ration may not always depend upon its capacity to form an increase. It may be decidedly to the farmer's advantage to enrich the food with such materials as bran and highly nitro-

genous foods for the purpose of increasing the value of the manure produced, and in this way to maintain and increase the fertility of the land.

Before leaving this subject it may be valuable to call attention to the relative efficiency of the different classes of farm animals as transformers of food into body increase. Warington furnishes some interesting data on this point:—

	<i>Per 1000 lbs. live weight per week</i>			<i>Required to produce 100 pounds increase</i>	
	Dry matter consumed	Digested organic matter	Increase in live weight	Dry food consumed	Digested organic matter
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Oxen.....	125	88	11.3	1,109	777
Sheep.....	160	121	17.6	912	686
Pigs.....	270	227	64.3	420	353

It will be seen that in proportion to its weight, the sheep eats more food and yields more increase than the ox, while the pig consumes more food and returns much more increase than either. This is due to the concentrated and easily digestible character of the food supplied the fattening pig. It must expend comparatively little energy in preparing the material for assimilation. Again, the digestive apparatus of ruminants is anatomically different from that of the pig. In the former the capacity for the storage of rough fodders is large, but the proportion of intestine, where absorption is most active, is much smaller than in the pig.

Requirements for wool production. Wool is the hair of sheep; but the hair of certain goats, such as the alpaca, cashmere, and mohair, as well as that of the camel, is also classed as wool. Wool differs from ordinary hair only in its physical structure, being covered with minute, overlapping scales, and having a twisted or curled fiber. Wool has great affinity for water and may contain from 8 to 12 per cent of moisture in hot, dry weather, and up

to 50 per cent in damp weather. Raw wool consists of (1) yolk or wool-grease; (2) suint; and (3) the pure wool hair. The first two may constitute from 30 to 80 per cent of the weight of the unwashed wool. The yolk is made up of fatty or wax-like bodies, of complex composition and insoluble in water. In a washed fleece the yolk may vary from more than 30 per cent to less than 8 per cent. Short fine wool contains the largest proportion of yolk. The suint is an excretion of the perspiration glands of the skin and consists of potassium salts of fatty acids, together with phosphates, sulphates and chlorides. It is soluble in water and consequently, removed by washing. It may amount to 50 per cent of the weight of unwashed wool, but with a sheep exposed to the weather, the quantity may be 15 per cent or less.

The pure wool fiber is, for the most part, a protein and contains about 16 per cent of nitrogen and 3.6 per cent of sulphur. A large proportion of the nitrogen of a sheep's body is found in the wool. The fact that wool production is at the expense of proteins must indicate that a somewhat narrower ration is demanded than for mere fattening. Wolff fed two sheep on rations consisting of hay and bean meal, which supplied proteins liberally and maintained the weights of the animals. Two others received at the same time, oat straw and roots, and lost slightly in weight. The yield of pure wool fiber in the first case was 12.9 pounds and in the second 10.0 pounds. It appears from this that under poor treatment the yield of wool will be seriously diminished. Experiments further show that on liberal fattening rations, the production of wool is no greater than when the ration is just sufficient to maintain the animal. However, from the experiments of others, it appears that on somewhat scanty rations, the body may lose weight without the production of wool being seriously affected. All this emphasizes the fact that for the health and vigor of the animal producing this nitrogenous coat, the protein supply must not fall too low.

The high favor in which such root crops as turnips and rutabagas are held by sheep feeders may find its explanation in their

richness in sulphur, which we have seen constitutes a considerable proportion of the pure wool fiber.

Requirements for milk production. Milk ultimately comes from the food and its direct purpose is for the nutrition of the young. For this reason its production, so far as possible, is made independent of the immediate food supply. If the surplus food given a fattening ox is withdrawn to a maintenance requirement, the laying on of increase will immediately cease; but the food of a milking cow may be reduced to maintenance, without stopping the production of milk. The animal will continue to produce milk, drawing for its source from her own body. The quantity produced will decrease and the animal will steadily grow thinner. A minimum food supply will not entirely stop milk production. neither will an over-abundant supply raise the milk production beyond certain limits. Each cow has an inherent milk producing capacity, determined by breed and individuality. Above this it is rarely possible to go, but whether this capacity is reached will depend upon food and treatment. Excess of food will simply tend to fatten. Generous feeding will not make a good milch cow out of a poor one, but it will sustain a full flow of milk and extend the period of profitable production.

There is only one way to determine whether a cow is profitable, and that is by determining her yield of milk and the amount of marketable constituents it contains. To-day, this is entirely done on the basis of the quantity of fat the milk contains, which gives the animal's capacity for butter production. To measure the capacity of her milk for cheese production, both fat and casein must be determined. From the standpoint of economy in transforming feed stuffs into human food, the total milk solids, and not the milk volume, should be the basis for estimation.

The quantity of nutrients necessary to make 100 pounds of Jersey milk, other things being equal, is greater than that required to produce the same weight of Holstein milk. From the standpoint of the farmer the most profitable cow is the one pro-

ducing the largest return in butter fat, butter fat and casein, or total milk solids *per unit of food consumed*.

The transformation of digestible feed material into human food by the dairy cow far exceeds that produced in the same time by the growing or fattening ox and slightly exceeds that produced in swine. An ox, gaining 2 pounds per day, will yield in edible solids about 1.5 pounds, while a dairy cow, producing 30 pounds of milk containing 12 per cent of solids, will yield 3.6 pounds. Based on pounds of digestible nutrients consumed, Jordan has given us some interesting figures. They are general averages and are given in the following table; they represent the pounds of edible solids produced by 100 lbs. of digestible organic matter in the ration.

Relation of Food to Produce.

	Edible solids Lbs.
Milk	18.0
Steers, (carcass).....	2.52
Lambs	2.60
Swine	15.60
Calves.....	8.10
Fowl.....	4.20
Eggs	5.10

The quantity of solids in the cow's milk, per unit of feed consumed, thus always exceeds the quantity of solids produced in the increase of the fattening ox, and in the order of food efficiency the cow leads the list.

Milk is a highly nitrogenous substance, and its proteins must be made from protein. They can have no other ultimate source but the feed and cannot be produced from fats or carbohydrates. Thirty pounds of average milk will contain a pound of protein. This daily drain means that the ration of the dairy cow must be reasonably narrow. If 0.6 pound of protein is needed for maintenance, then 1.6 pounds must be used daily. Practice and science have established the quantity of digestible organic matter

necessary for economical milk production at from 15.5 to 16.5 pounds per day for a good cow of average size. The quantity required may vary somewhat according to size,—a small cow requiring proportionately somewhat more than a larger one for the same yield of milk,—but *capacity* for production is the more important factor in determining the quantity of feed required. With that amount of digestible nutrients, the nutritive ratio would be about 1:9.5. Careful experiments, however, show that a nutritive ratio of 1:5.5 to 1:6.5 is more efficient than the wider one, and that a cow of average size and good capacity should receive at least 2.25 pounds of digestible protein daily, with a nutritive ratio not wider than 1:6.5. Young pasture grass, well known to be an efficient milk producer, is even narrower than this. The function of this additional protein is not known, but the accepted axiom that proteins stimulate the metabolic activities of the cells is borne out here, with an intensified milk secretion as the result. On the other hand, excessive protein feeding may be injurious and certainly is not necessary.

It has been taught that the fats of milk originate from the protein and food fats. If true, this would increase the demand for protein, but experiments have clearly demonstrated that they are not a necessary source of milk fat. In a carefully conducted experiment at the New York Experiment Station, Jordan conclusively showed that the carbohydrates of the food could serve as milk-fat formers.

The food consumed by the dairy cow during the first half of the lactation period is largely used in milk production, but during the latter portion of lactation it is partly consumed in building the calf, and the return in milk is reduced. A newly-born calf weighing 80 pounds, may contain 20 pounds of protein, 3 pounds of fat, and the rest will be water and ash.

From what has been said on the necessity of a proper protein supply for the milch cow, it is apparent that where the home grown crops are the hays made from true grasses and where the corn crop is the chief one raised, then home-grown rations for

maximum efficiency in milk production are not possible. Where, however, alfalfa and clover make the hay, and peas and oats are grown, a protein supply consistent with efficiency can be produced.

There is the additional fact that the production of milk demands a plentiful ash supply to the animal. Thirty pounds of milk will contain nearly an ounce of lime and the same quantity of phosphoric acid. Besides the quantities secreted in the milk, there is apparently a waste from cell activity, which in the case of a dairy cow yielding 30 pounds of milk, was found to be nearly equal to the quantity secreted in the milk. In an experiment at the Wisconsin Station, where a ration was made up of oat straw, rice, wheat bran and wheat gluten, a cow continued to give a milk of constant composition in respect to lime content, as well as all other constituents; yet the amount of lime supplied the animal, for a period of over 100 days, had been deficient. To maintain a normal composition of the milk, the animal had withdrawn lime from her skeleton, a remarkable transmigration of material. The health of the animal was apparently unimpaired, but it is self-evident that ultimately the milk flow must have ceased or the animal would have collapsed. While the ration used was unusual, the experiment, however, emphasizes the necessity of a liberal supply of ash material for the dairy cow. The legume seeds and cereal grains are low in lime, but are fairly rich in phosphorus. Wheat bran is relatively poor in lime, but rich in phosphorus. Ten pounds of bran will supply about one-fourth of an ounce of lime, but nearly one-third of a pound of phosphoric acid. The hays from the true grasses are fairly well supplied with lime, but the legume hays, as clover and alfalfa, are particularly rich in this material, and should, for this reason, form a part of the ration of the dairy cow.

It would appear, then, that in most rations recognized by dairymen as efficient for milk production, phosphoric acid and lime will be plentifully supplied, especially where bran and the legume hays constitute a part of the ration. But should straws form the roughage, the supply of lime may become deficient.

CHAPTER XII

MILK AND ITS PRODUCTS.

Milk is a valuable agricultural product and both it and the products obtained from it are of considerable commercial and industrial importance. The dairy products of the State of Wisconsin alone are valued at \$75,000,000.

Secretion. Milk is the secretion of special glands in the mammalian female and adapted to the nourishment of the newly born young of that particular species. The constituents of the milk are especially elaborated by the cells of the mamma; these constituents do not exist preformed in the blood, but are formed by profound chemical processes, little understood, out of the nutrients carried in the blood to the active cells. For example, no casein or milk sugar exists either in the food of the cow or in her blood, but from the nitrogenous constituents of blood, the complex protein, casein, is elaborated; also, from the simple sugar dextrose, the more complex milk sugar is formed. This is all accomplished through the wonderful activities of the udder cells. That the composition of the milk is closely related to the food requirements of the newly born young and its rate of growth, has been suggested by the physiologist, Bunge. This relates particularly to the ash and protein materials of milk, which are so necessary for the life processes and the rapid building of the growing young.

The following table will clearly show that the ash of milk and of the new born young are very much alike, while they have an entirely different composition from the fluid out of which they are formed, namely the blood, and especially the blood serum; from a consideration of such facts, it appears certain that the cells of the milk gland must possess the power of selection and that milk is not merely filtered from the blood.

*Comparative Composition of the Milk, Blood and Body
of the Same Animal.*

	<i>100 Parts by weight of ash contained in grams</i>			
	Dog a few hours old	Dog's milk	Dog's blood	Dog's blood serum
Potash	11.14	15.0	3.1	2.4
Soda	10.6	8.8	45.6	52.1
Lime	29.5	27.2	0.9	2.1
Magnesia	1.8	1.5	0.4	0.5
Phosphoric acid	39.4	34.2	13.3	5.9

If we compare the time required by the suckling to double its weight at birth, with the amounts of protein and ash—perhaps the most essential constituents for the formation of tissue—contained in 100 parts of milk, it is evident at a glance that the amounts of these increase in proportion to the rate of growth of the animal. This is shown in the following table:—

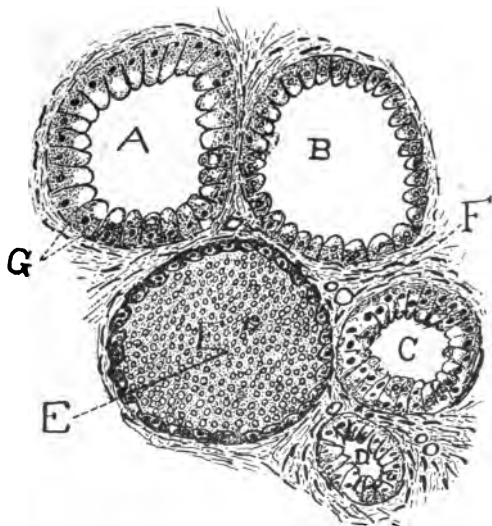
Composition of Milk Ash from Different Animals.

Species	Days required to double weight	<i>100 parts by weight of milk contains in grams</i>			
		Protein	Ash	Lime	Phos- phoric acid
Man	180	1.6	0.2	0.03	0.05
Horse	60	2.0	0.4	0.12	0.13
Cow	47	3.5	0.7	0.16	0.20
Goat	22	3.7	0.78	0.20	0.28
Sheep	15	4.9	0.84	0.25	0.29
Pig	14	5.2	0.80	0.25	0.31
Cat	9½	7.0	1.02	.....	.....
Dog	9	7.4	1.33	0.45	0.51
Rabbit	6	14.4	2.50	0.89	0.99

The composition of the milk of a single species is by no means similar to that of another, although the constituents forming it, so far as they have been investigated, are of a similar nature.

The constituents of milk may be divided into the following classes: water, fats, proteins, sugar and ash. The water of milk constitutes from 85 to 88 per cent and needs no discussion.

Fats of milk. The fats resemble in chemical constitution the animal and vegetable oils and fats already discussed; that is,



The milk chambers or alveoli of an udder; A and B, secreting alveoli; C and D, non-secreting alveoli; E, alveolus, which has discharged its milk (cells appear flattened).

they consist of compounds of fatty acids and glycerine. They differ from animal fats chiefly in containing acid radicals of low molecular weight, in addition to the heavy acids, such as oleic, stearic, and palmitic, which are the principal fatty acids in the fats of animal tissue. Butter fat consists of the glycerides of at least 9 fatty acids. The lowest member of the group is butyric acid, the highest is stearic acid. Oleic acid belongs to another

series. The average percentage composition of milk fat is about as follows:—

<i>Per cent</i>				<i>Per cent</i>	
Butyrim	3.85	Myristin	20.20		
Caproin	3.60	Palmitin	25.70		
Caprylin	0.55	Stearin	1.80		
Caprin	1.90	Olein	35.0		
Laurin	7.40				

The properties of these fats are variable, but the important fact to notice is the occurrence in milk fat of the first three or four fats in the above list, but mere traces of which are present in other animal fats. Olein and the first four members of the above list are liquid fats; the others are solid, stearin being the hardest. About 8.0 per cent of the fatty acids, chiefly consisting of the first three in the series, are soluble in water. The soluble acids have a low boiling point and can be separated from the other fatty acids by distillation. These facts serve to distinguish butter fat from animal fats such as tallow, which contains but traces of soluble and volatile fatty acids. Milk fat, however, varies considerably both in composition and physical properties, being affected somewhat by feed, period of lactation and other circumstances under which the cows are kept.

Fat exists in milk in the form of minute globules, varying in diameter from .0016 to .010 m. m. In the milk of Jersey and Guernsey cows the average size of the globules is considerably larger than in Holstein milk; also in the milk of recently calved cows the globules are larger than in that of cows far advanced in lactation. This fact has an important practical bearing upon the speed with which cream rises. The milk of the Jerseys and Guernseys throws up its cream very rapidly, while from the milk of the Holstein and Ayrshire breeds the cream rises relatively slower.

The proteins. The two most important proteins of milk are casein and albumin. Traces of others are present, but they are

in such relatively small quantities that they will not be discussed here.

Casein is the chief protein of milk and exists there in a colloidal state and not in perfect solution. It can be separated from the milk by the addition of an acid or by the action of the enzyme, rennin, which is contained in rennet. In the souring of milk, during which process acid is developed, the casein is precipitated. The casein formed in this way probably consists of calcium-free casein, for it is generally held that casein exists in milk in combination with calcium. With rennin, however, the calcium-casein is split into two compounds, para-casein and whey protein. The para-casein in the presence of the soluble calcium salts of the milk precipitates out, while the whey protein remains in solution. In the absence of calcium salts rennin will not curdle milk. This enzyme acts best at 35° C. and is destroyed at 70° C. It is found in the stomachs of all mammals, while enzymes possessing similar properties have also been found in birds, fishes, many plants, and in the products formed by the action of certain bacteria.

Mere boiling of milk, unless continued for a considerable time, does not coagulate the casein. Casein is the only protein of cow's milk which contains phosphorus in its molecule.

Milk albumin differs in some of its physical properties from blood albumin. It is in complete solution in milk but coagulates and precipitates when heated to 72° C. It is not coagulated by rennin or by most acids. It differs from casein in composition and contains about twice as much sulphur and no phosphorus. In colostrum milk, albumin largely predominates, so that the milk coagulates on heating.

Milk sugar. The sugar contained in milk is known as lactose. It occurs in the milk of all animals, but is not present in plants, and consequently does not exist in the food of the dairy cow. It is prepared by evaporating the whey, left after cheese making, to a small bulk, from which lactose will crystallize out in large crystals. It possesses a faint sweet taste, about one-tenth that

of cane sugar. By the action of dilute acids or an enzyme known as lactase, it is split into a mixture of dextrose and galactose.

Milk sugar does not readily undergo alcoholic fermentation, but is readily changed into lactic acid by certain micro-organisms. This change in the milk sugar is the cause of milk souring. The necessary lactic organisms are very abundant everywhere, especially in the vicinity of dairies and barns, and as they multiply in the milk, more and more lactic acid is formed. Sweet milk has an acidity of from 0.12 to 0.20 per cent, expressed as lactic acid. When about 0.40 per cent is present, the milk acquires a sour taste, and when the amount reaches 0.6 to 0.7 per cent, curdling commences. With certain organisms, the amount of lactic acid may reach from 2.0 to 3.0 per cent, but ordinarily it does not exceed 0.9 per cent.

The ash of milk. When water is removed from milk by evaporation and the residue then burned, a white ash is always left behind. This consists of the mineral matter and salts of the milk, together with sulphates, phosphates and carbonates produced by the burning of the organic matter of the milk. It amounts in cow's milk to about 0.7 per cent, and consists of:—

	<i>Per cent</i>		<i>Per cent</i>
Potash	22 to 27	Ferric oxide.....	traces to 0.2
Soda	10 to 12	Sulphur trioxide.....	3.8 to 4.4
Lime.....	19 to 24	Phosphoric acid.....	22 to 27
Magnesia.....	1.8 to 3	Chlorine.....	13 to 16

Milk also contains traces of citric acid. This is not free, but in combination with bases as citrates and amounts to about 0.1 per cent of the milk.

The gases of fresh milk are chiefly carbon dioxide, oxygen and nitrogen. These amount to about 85 c. c. per liter, the carbon dioxide constituting approximately 90 per cent of the total gas. On standing, or even during the process of milking, there is a rapid exchange of gases, the carbon dioxide greatly diminishing, while the oxygen and nitrogen rapidly increase. This increase

in oxygen and nitrogen is really an absorption of air and emphasizes the necessity of maintaining a pure, sweet atmosphere, to which fresh milk is to be exposed.

Physical properties. Milk is a white, or yellowish white, opaque fluid, with a sweet taste. The specific gravity varies usually from 1.027 to 1.034. The solids other than fat tend to raise the specific gravity, while the fat tends to lower it. As cream may be removed and water added without altering the specific gravity, no safe conclusion as to the quality of the milk can be based on this test alone. When fresh milk is quickly cooled and its specific gravity taken at once, and then again after some hours and at the same temperature, a small but decided rise in density is observable, usually amounting to about 0.0005. This is known as Rechnagel's phenomenon, and has been explained in several ways. It has been ascribed to the escape of gases from the milk; to a change in the mechanical condition of the casein; and lastly to the solidification of the fat globules. It is suggested that quick cooling does not immediately solidify the fat globules, which are liquid at the temperature of the cow, but that they remain in a super-cooled liquid state. As they slowly solidify, they contract, thereby increasing the density and raising the specific gravity.

Chemical composition. This varies considerably according to breed, individuality, age, period of lactation and food. The mean composition, according to many American analyses, is as follows:—

	<i>Per cent</i>		<i>Per cent</i>
Water.....	87.1	Casein	2.5
Fat	3.9	Albumin	0.7
Sugar	5.1	Ash	0.7

It must be remembered that these figures, being averages, imply the existence of many values either above or below those given. As a rule the fat is most liable to variation. The factors influencing the composition of milk will be briefly discussed under the following heads:—

Breed. It is well known that breed is a very important factor in influencing the composition of milk. The following table gives the average composition of the milk from several individuals of the breed represented. Individual variations from the figures given are of course to be found, and the figures only represent the general trend of the breed.

Composition of Milk of Different Breeds.

Name of breed	Solids	Fat	Casein	Albumin
	Per cent	Per cent	Per cent	Per cent
Holstein	11.80	3.26	2.20	.64
Ayrshire	12.75	3.76	2.46	.61
Shorthorn	14.30	4.28	2.79	.64
Devon	14.50	4.89	3.10	.83
Guernsey	14.90	5.38	2.91	.65
Jersey	15.40	5.78	3.03	.65

Individuality. It is uncommon to find in a herd of cows of the same breed any two individuals whose milk is of the same composition. This is true whether we consider single milkings or the average of many.

Age. So far as there are published data on the influence of the age of cows on the composition of milk, they indicate a tendency for the heifer to show a slightly higher fat content than the mature cow. Individual exceptions, however, are not infrequent, and more data are needed to settle the question.

Period of lactation. Immediately after calving, the first product of the udder is colostrum. This is a yellow liquid, of strong, pungent taste, and very different from normal milk. It is characterized by containing small clusters of cells, known as "colostrum granules" and is very rich in albumin. This may reach 13.5 per cent. Because of the high content of albumin, colostrum milk sets to a solid mass on heating. This test serves to distinguish it from normal milk. This first milk is exceedingly important to the young animal at birth, and serves to

cleanse the alimentary tract and properly start the work of digestion. After eight or ten days from calving the secretion becomes like normal milk, but the colostrum cells can usually be found in the milk for about 14 days after calving.

The milk during the first month after calving is generally rich in fat and total solids, and these diminish during the second month. After the second or third month, the fat and protein, as well as the sugar, continue to increase from month to month during the entire period of lactation. The following table, taken from the data of the New York State Station, represents the monthly averages of nearly 100 different lactation periods.

Influence of Lactation on the Composition of Milk.

Month of lactation	Fat	Proteins	Casein	Albumin
	Per cent	Per cent	Per cent	Per cent
1.....	4.30	3.16	2.54	0.62
2.....	4.11	2.99	2.42	0.57
3.....	4.21	3.04	2.46	0.58
4.....	4.25	3.13	2.52	0.61
5.....	4.38	3.25	2.61	0.64
6.....	4.53	3.36	2.68	0.65
7.....	4.57	3.40	2.74	0.66
8.....	4.59	3.47	2.80	0.67
9.....	4.67	3.57	2.90	0.67
10.....	4.90	3.79	3.01	0.78
11.....	5.07	4.04	3.13	0.91

Occasionally individuals may depart from the general tendency shown in the above table, but usually they conform to the general rule which the table indicates. The average size of the fat globules diminishes with advancing lactation, but their number per unit volume increases.

Feed. The influence of the feed of cows upon the composition of their milk is a matter upon which many varied opinions are held. There is a widespread belief that this influence is considerable, but all experimental evidence shows it to be very small. Under scanty food supply the quality and especially the quantity

of milk may be considerably reduced. This is evidenced by the results secured at the Cornell Station with a poorly fed herd and again when the same herd was liberally fed. Under those conditions, where a liberal supply of nutrients was given, the flow of milk was nearly doubled and the percentage of fat slightly increased. Again, there appears to be some distinct evidence that a change from a ration with a wide nutritive ratio to one with a narrow ratio, is for a time, attended with a production of milk slightly richer in fat; but the change is only transient, and even if the food with a high protein ration be continued, the milk, after allowance is made for the effect of advancing lactation, shows a tendency to return to its previous composition.

In any case, it appears that, provided cows are sufficiently fed, change of feed has very little permanent effect upon the composition of their milk. Violent and sudden changes in the character of their feed may cause a sudden fluctuation in the composition of the milk, but after a short period it will tend to return to a composition characteristic for that animal.

The opinion that it is possible to feed fat into milk has widely prevailed, but such a notion is based upon a misconception of how milk is formed. When, however, we remember that the cells of the mammary gland are selective in function, and that with the same feeds a Jersey cow always makes Jersey milk, and a Holstein cow Holstein milk, then the many failures to feed fat into milk become intelligible. The careful and well planned work of Lindsey, in which a number of vegetable oils have been added to a basal ration, gave in some cases slight but only temporary increases of fat in the milk, while with other oils no increase whatever was noticed.

Certain feeds, however, affect the character of the fat in the milk, which is manifested by a change in the hardness and physical properties of the butter produced. It is agreed that cottonseed meal has the effect of raising the melting point of butter, while gluten feed, rich in oil, produces a softer butter of lower melting point. In experiments at the Wisconsin Station, long

continued feeding of nutrients entirely from the corn plant, as well as from the wheat plant, tended to produce soft, low-melting milk fats, while the nutrients from the oat plant produced fats making a hard butter, with a high melting point.

Season. The influence of season upon the composition of milk, apart from the effect of advancing lactation, is largely associated with the food supply. When this is normally maintained and the animals are protected from the effect of weather changes, variations in the composition of the milk appear to be slight.

Time and intervals between milking. Where the time between milkings is the same and there are no other disturbing influences, the composition of morning's and evening's milk shows practically no difference. Where the intervals are unequal, there may be a considerable variation in the two milkings. In an experiment where 17 Shorthorn cows were milked at 6 a. m. and 3 p. m. the average per cent of fat in the morning's milk was 3.2, and 4.5 per cent in the evening's milk.

It is well known that the first milk drawn from the udder at milking time is very low in fat, sometimes being as low as 1 per cent, while the last portion may contain as high as 10 per cent. In these two fractions, however, the other constituents are in about the same proportion as would be found in the entire milking.

Milk of other animals. The following table compiled from several sources, gives the average composition of the milk of other animals; some of the results are probably not truly representative, due to improper sampling.

There is a considerable difference in the behavior of the casein of the milk of different animals when treated with rennet. With cow's milk the enzyme of rennet, rennin, gives a coherent, curdy precipitate, while with human milk the coagulum is much more finely divided. To this fact has been attributed, in part, the non-adaptability of cow's milk to infant feeding. It will also be noticed that cow's milk differs from the natural food of the human infant in containing more ash and proteins and much less

sugar. It is upon these chemical facts that the modification of cow's milk, by dilution and addition of lactose, rendering it suitable for infant feeding, is based. However, experience is teaching that in most cases the whole milk of the cow, without dilution, can be safely used for infant feeding. There is a growing belief, though, that it must not be too rich in fat.

Preservation of milk. Normal milk as it occurs in the cow's udder usually contains relatively few organisms; but in the

Composition of Milks.

Animal	Fat	Casein	Sugar	Ash	Solids not fat
	Per cent	Per cent	Per cent	Per cent	Per cent
Woman.....	3.3	1.5	6.8	0.2	8.5
Ass.....	1.0	1.1	5.5	0.4	7.8
Goat.....	6.5	4.3	5.0	0.7	10.2
Ewe.....	5.3	7.1	4.2	0.8	12.4
Mare.....	1.7	2.2	6.0	0.4	8.6
Sow.....	4.6	7.2	3.1	0.8	11.4
Camel.....	2.9	3.8	5.7	0.6	10.2
Hippopotamus.....	4.5	Trace	4.4	0.1	4.5
Bitch.....	9.6	9.9	3.2	1.3	13.8
Cat.....	3.3	9.5	4.9	1.0	15.0
Rabbit.....	10.5	15.5	2.0	2.5	20.1
Elephant.....	19.6	3.1	8.8	0.6	12.6
Porpoise.....	48.5	11.2	1.3	0.5	13.1
Whale.....	43.7	7.1	.....	0.4	7.7

operation of milking and during subsequent exposure to the air, bacteria, molds and yeasts find admission. They may find their way into the milk from the hands of the milker, the teats and hair of the cow, and often from the vessel in which the milk is collected. The ordinary souring of milk is produced by various species of bacteria, which during their growth convert the milk-sugar into lactic acid. This formation of acid induces the curdling of the milk. This generally occurs when the amount of acid reaches about 0.7 per cent. Curdling is produced by less acid if the milk is heated.

Other organisms, and often of a more dangerous character,

sometimes find their way into milk. Outbreaks of diarrhoea, typhoid and cholera have been traced to contaminated milk. It has also been shown that milk can act as a carrier of tuberculosis. Milk, too, has the property of absorbing gases and vapors and in consequence readily acquires odors and flavors from the air.

All these facts emphasize the necessity of cleanliness in milk production and precautionary measures to check bacterial development should the milk become seeded. Their growth can be checked by cooling the milk as soon as it is produced. This prevents a rapid development of the organisms already in the milk, but will not entirely prevent their development. It will prolong the sweetness of the milk. In order to destroy the organisms which have gained access to the milk, heating or the use of antiseptics must be resorted to. Where the process of heating is carried on at a temperature high enough to completely destroy all organisms and their spores—a process known as sterilization and requiring a temperature above 100° C.—undesirable chemical changes are produced in the milk. The sugar is turned brown, the albumin partly precipitated, and the milk acquires a burnt or cooked flavor. To avoid these disadvantages the process known as Pasteurization is often substituted. The milk is heated to only 60 to 80° C., whereby the flavor is little affected and most of the active bacteria are killed. The keeping qualities are thus materially increased.

Antiseptics. By adding various substances to milk, the growth of micro-organisms can be impeded, if not entirely prevented. When, however, such quantities of an antiseptic are added as will prevent bacterial growth, then there is little doubt that the milk is made unsuitable for human consumption. The chief preservatives in common use are boric acid, salicylic acid, formaldehyde and benzoic acid. Their use in any quantity is reprehensible, allowing uncleanly methods in milk production to be practiced, as well as endangering the health of the consumer, and should be absolutely prevented.

Products derived from milk. Cream. The fat of milk exists in globules and is specifically lighter than the aqueous portion of the milk. This makes the globules tend to rise to the surface, where they form a layer of cream. The specific gravity of fat at 15° C. is .930, while the serum in which the globules float has a specific gravity of about 1.036. The globules are of various sizes. They are considerably larger in the milk of the Jersey and Guernsey breeds than in the Ayrshire and Holstein breeds. The Devons and Shorthorns hold an intermediate position. The smaller the globule, the larger is its surface in proportion to its volume, and the greater the resistance to its rise. For this reason Jersey milk creams easier than that from breeds with smaller globules.

Cream can be separated from milk by gravitation or by substituting for gravity the much greater force produced by rapid rotation. When milk leaves the cow it will have a temperature of about 90° F., and where set for cream should be cooled as quickly as possible. There are two methods in use for the separation of cream by the gravity processes, namely, *shallow setting* and *deep setting*. In the former the milk is placed in shallow vessels to a depth of 2 to 4 inches, cooled to about 60° F. and kept at that temperature for 24 or 36 hours. The cream layer is then removed by a shallow spoonlike vessel, or sometimes by running off the milk into another vessel through a hole at the bottom of the creaming pan. Under these conditions of creaming a large surface is exposed, the milk may receive a great number of bacteria, and decomposition of a part of the protein and sugar may rapidly take place. The cream obtained in this way is liable to be contaminated with various strongly flavored products of decomposition, resulting in a poor quality of butter. The process is not efficient, as only about 80 per cent of the milk fat is removed.

By the deep-setting system, the milk, while still warm, is placed in cylindrical vessels, usually about 8 to 12 inches in

diameter and 15 to 20 inches deep, which are then immersed in ice-cold water. The cream rises quickly and the process will be practically complete in 12 hours. By this process 90 to 95 per cent of the fat can be removed, dependent upon conditions of cooling, manipulation, and the breed of the cow. It has been found that by this process twice as much fat remains in the skim milk from Holstein cows as in that from Guernseys and Jerseys, owing to the slower rising of the small fat globules in Holstein milk.

Many explanations of the efficiency of this system have been attempted. Since fat expands and contracts with changes of temperature more rapidly than does water, the effect of cooling upon milk would be to lessen the difference in specific gravity between fat and water; it would also increase the viscosity of the milk, both conditions working against a rapid rise of the fat globules. Perhaps the most satisfactory explanation is the one given by Doctor Babcock. There exists in milk a substance similar in character to blood fibrin, which, when formed produced more or less of a network throughout the body of the milk. By rapidly cooling the milk, the formation of fibrin threads is checked. This allows the fat globules a free path of movement, with the resultant rapid formation of the cream layer. The existence of fibrin in milk has been definitely proven.

Separators. A third plan of separating cream is by subjecting the milk to extremely rapid horizontal revolution in a centrifugal machine. Under this condition the serum, being the constituent of heaviest specific gravity, is thrown to the outer side of the revolving vessel while the fat globules rise into the center of the mass. The milk should be warmed to about 85° F. previous to separating, for the purpose of lowering its viscosity. By providing suitable outlets, the skim milk can be directed into one channel and the cream into another. By adjusting the size of one of these openings, thick or thin cream can be obtained at will. Both the cream and skim milk thus obtained, are, of course, perfectly sweet. The separation of the fat is far more complete

than by either of the other processes, from 97 to 98 per cent being recovered in a good machine.

Composition. Cream varies enormously in composition, the proportion of fat varying from as low as 10 per cent to as high as 60 or 70 per cent. By shallow setting, a product containing from 15 to 40 per cent is usually obtained; at low temperatures about 20 per cent of fat is usually present. In the deep-setting process the cream obtained will contain about 20 to 25 per cent of fat. Cream separated by the centrifugal process will vary according to the mode of working. It may be quite poor, or it may contain 50 to 60 per cent. Generally speaking, thin cream will contain 15 to 25 per cent of fat, and thick cream 30 to 50 per cent of fat.

Devonshire-“clotted cream” is prepared by setting the milk in shallow pans and at a fairly cool temperature for 12 hours. It is then heated to a temperature of 70 to 80° C. until the surface becomes sharply wrinkled. It is then set in the cold for 12 hours and skimmed. Such clotted cream usually contains about 58 per cent of fat, 34 per cent of water and about 8 per cent of solids not fat.

Skimmed milk varies in composition according to the more or less complete removal of the fat. Milk thoroughly skimmed after shallow setting will contain about 1 per cent of fat. With deep setting and ice, the per cent of fat left in the milk will vary from 0.15 to 0.40. When the centrifugal machine has been used the percentage will be from .05 to .15. Milk of average quality may be expected to yield with a good centrifugal machine, skimmed milk of about the following composition:—

	<i>Per cent</i>		<i>Per cent</i>
Water.....	90.54	Casein	3.11
Fat	0.10	Albumin	0.42
Sugar	4.94	Ash, etc.....	0.89

Skimmed milk contains a valuable amount of food stuffs, and should be utilized on the farm for feeding pigs or in other ways. Though poorer in fat, machine separated milk has the advantage

of being sweet and of keeping better than the product from other processes of skimming.

Butter. When cream or milk is agitated for some time, the fat globules coalesce and butter separates out in irregular masses. While these masses are not continuous fat, very few of the original globules remain. The spherical globules visible in butter under the microscope consist of minute drops of butter-milk or water, enclosed in the fat.

Churning is a mechanical process. The fat globules collide, adhere, and the large irregular masses thus formed become centers of growth, to which other fat globules adhere. Portions of the aqueous liquid, butter-milk, are enclosed in the masses of fat. During the "working" of the butter, the butter-milk is partly pressed out. For butter to be of good quality, it must possess a certain texture and grain and be neither hard nor greasy. This desirable result can only be attained by careful churning at a favorable temperature. If the temperature of the cream is too low the butter will be long in coming and will be hard in texture. If the temperature is too high, the butter will come very speedily, but the product will be greasy and destitute of grain. No temperature can be fixed as the best at which churning should always take place. The proportion of solid and liquid fats in the milk varies somewhat with the breed and feed of the cow, and this necessitates a change in the temperature. From 45 to 65° F. is the greatest range usually employed and, in most cases from 50 to 60° F. is chosen. "Ripened" or sour cream must be churned at a higher temperature than that required for sweet cream. The exact temperature most suitable for churning may be ascertained, by recording every day the temperature employed, the length of time occupied in churning and the character of the product. When this is done the experience gained can be used in selecting the most suitable temperature.

The temperature may rise during churning, work being converted into heat. This causes an expansion of the air in the churn. In addition, the carbon-dioxide in solution in the serum

of a ripened cream is driven out by the agitation. These two factors give rise to the pressure observed within the churn. Churning should always be stopped as soon as the butter appears in fine grains. This allows a more complete separation, by washing, of the butter-milk, and removes one of the important factors in the production of mottles in butter. Further, the more completely the butter-milk is removed, the better will be the keeping qualities of the butter.

Freshly separated cream is sometimes churned, but it is generally admitted that the best flavor and aroma for butter can only be obtained by the use of properly ripened cream. This is, cream to which lactic acid organisms have either gained access spontaneously, or, as is preferred in modern practice, have been added in the form of a "starter" of sour skimmed milk or some pure culture of the lactic organisms. The degree of ripeness which is probably best, corresponds to about 0.5 per cent of lactic acid; but the acidity most suitable depends to some extent upon the flavor desired in the butter. If the cream is over ripe, the casein present may be hardened and on churning is found as white specks or flakes in the butter, spoiling its appearance and endangering its keeping qualities.

Salt is usually added to butter, serving both as a condiment and as a preservative, the proportion varying from a mere trace to 5 or 6 per cent.

Composition of butter. The main constituent is of course fat, but in addition, water, casein, milk sugar and ash are also present. The amount of fat is usually about 80 to 86 per cent, water about 11 to 12, casein from 0.6 to 1.5 and salt from 0.1 to 4.0 per cent. Under the present pure food law of the United States it is unlawful to sell butter containing more than 16 per cent of water. So called "milk-blended butters" prepared by kneading butter in milk, usually contain an excessive quantity of water and a high proportion of casein.

Renovated butter. In this country old and rancid butter is sometimes converted into what is known as "renovated," "pro-

cess," or "aerated" butter. This is done by melting the butter, separating the fat from the casein, water, etc., blowing air through the fat to remove the unpleasant odors, and then churning the liquid fat with milk until an emulsion is formed. This is then quickly cooled in ice and a granular mass results. It is then worked, salted, and made up as butter.

Oleomargarine is also known as "margarine" or "butterine." This product, which is intended as a substitute for butter, is made by churning so called "oleo oil" with lard, milk, sometimes a little butter, and occasionally cotton-seed oil or peanut oil, in a warm state. After the churning the mixture is quickly cooled, salted and "worked." Where coloring matters are used, with the intention of imitating butter, a tax of 10 cents a pound is imposed. On uncolored "oleo" a tax of $\frac{1}{2}$ cent per pound is levied.

The "oleo oil" is made from beef fat by melting, carefully clarifying, and allowing it to stand at a temperature of about 30° C. The semi-solid mass which results is then separated by a press into solid stearin and a liquid composed of olein and palmitin.

Pure butter can be distinguished from "renovated" butter and from "oleo" by its behavior when heated in a test tube or spoon over a flame. Oleomargarine and renovated butter boil with much sputtering and produce no foam, or very little, while genuine butter in boiling produces more foam and less noise.

Butter-milk. The liquid remaining in the churn after the separation of butter from the cream varies a good deal in composition. With good churning of ripened cream, the percentage of fat in the butter-milk may be 0.3 or less. When sweet cream is churned 1.0 per cent of fat may be expected. The average composition of butter-milk will be about as follows:—Water, 90.9 per cent; proteins, 3.5; fat, 0.5; sugar and lactic acid, 4.4; ash, 0.7. The chief use for butter-milk has been as food for pigs, but there is a growing demand for it as human food. The finely

divided condition of its protein makes it readily and easily digestible. The preparation of a new product, butter-milk cream, will probably increase the consumption of this material as human food. This product is prepared by holding the butter-milk at 75 to 78° F. for about 2 hours, and finally heating to 130 to 140° F. for a short time. This treatment induces an aggregation of the finely divided protein, allowing the material to be strained and collected, which otherwise could not be done.

The following table shows how the various constituents of 100 pounds of milk are distributed when the milk is creamed and made into butter:—

Distribution of Milk Solids in Butter Making.

	<i>Products from 100 lbs. of milk, in lbs.</i>				
	100 lbs. of milk	20 lbs. of cream	Skimmed milk	Butter	Butter milk
Total solids.....	13.00	5.18	7.82	4.00	1.18
Fat.....	4.00	3.88	0.12	3.83	0.05
Casein and albumin.....	3.50	0.50	3.00	0.10	0.40
Sugar and acid.....	4.75	0.75	4.00	0.05	0.70
Ash.....	0.75	0.05	0.70	.....	0.03

The 4 pounds of solid matter recovered in the butter, which contains 3.83 pounds of fat, together with the salt and water present, make about 4.6 pounds of marketable butter.

Condensed milk and milk powders. Condensed milk is prepared by evaporating milk in vacuum pans until its volume is reduced to about one-third or one-fourth of the original, and then sealing the condensed product while hot. In many brands cane sugar is added in large proportion. This aids in preserving the product, even after the cans are opened. To other brands, often known as “evaporated cream,” no sugar is added.

The composition of these products varies, the fat being liable

to considerable variation. The following analysis may be taken as typical:—

	<i>Sweetened</i> Per cent	<i>Unsweetened</i> Per cent
Water.....	25.7	71.7
Fat	10.7	8.1
Protein.....	8.5	8.7
Milk sugar.....	11.9	9.9
Cane sugar.....	41.9	....
Ash.....	1.3	1.6

Milk powders are made by several processes. One of the earliest was to evaporate the milk in a thin layer, on a heated revolving drum. By this process the evaporation of water takes place rapidly and the dried film of milk drops, or is scraped, from the rolls, appearing as a thin yellow scale. Another process, of recent date, consists of atomizing the milk under pressure into a moving volume of warm dry air. The moisture is instantaneously absorbed and by the use of centrifugal force, the vapor charged air is made to give up the minute particles of suspended matter. The product is a fine flour, possessing, in common, with some other brands prepared by other methods, the properties of milk when again stirred up in water. There are preparations on the market which do not have these properties, probably because they have been subjected to too high heat in the drying process.

Of the several milk powders examined by the authors, only one contained any appreciable quantity of fat. It appears that most, if not all of these powders are prepared from skimmed, or partially skimmed milk. This is probably necessary, in order that dessication may be more complete and the keeping qualities of the product well insured. One product examined, and represented as a preparation from whole milk, contained but 9 per cent of fat. A milk powder prepared from average whole milk should contain at least 25 per cent of fat.

Various other dry foods are prepared from the casein of milk,

among which are "plasmon" and "nutrose." "Plasmon" is made by treating the curd of skimmed milk with sodium bicarbonate and drying the thoroughly mixed product in an atmosphere of carbon-dioxide. "Nutrose" is also a sodium compound of casein.

Cheese. The principal varieties of commercial cheese are prepared from milk by the action of rennet. Rennet is made by extracting the fourth stomach of the calf with a 5 to 10 per cent solution of common salt. Its power to coagulate milk is due to the presence of an enzyme called rennin, which plays a similar part in the process of digesting milk in the calf's stomach. Rennin coagulates the casein of the milk, forming a curd which mechanically entangles almost all the fat of the milk, leaving the albumin and sugar in the whey. Rennin acts more rapidly at about 102 to 104° F. In cold milk it is slow in its action, while at temperatures above 120° F. it is retarded, its action entirely ceasing at 130° F. In milk containing some acid, but not enough to curdle it, rennin action is hastened.

It is impossible in a work of this scope to describe the varieties of cheese and their methods of manufacture.

The common practice followed in the preparation of American cheddar cheese is to "ripen" the milk to an acidity corresponding to about 0.25 per cent of lactic acid. This is done by adding to it a starter consisting of sour milk or a pure culture of lactic organisms. The necessary rennet is then added, the milk being previously warmed to 82 to 85° F. After the curd is sufficiently firm, requiring about 30 minutes, it is cut into cubes and the temperature of the vat raised to 100° F. It is maintained at that temperature for 1 to 2 hours, during which time the curd shrinks and the acidity increases. After proper acidity is developed, the whey is drawn, the curd piled in one end of the vat and kept warm. In this condition it mats into a solid mass. It is finally passed through a grinding mill, salted, and pressed into molds. The cheese is then placed in a curing room at a temperature of 50 to 60° F. and allowed to ripen. A lower tem-

perature than this can be used, with great improvement in the quality of the product. In the manufacture of Swiss cheese the milk must be in a sweet condition. No acid is developed and the curd is cooked at a temperature of 125 to 130° F. The curd is placed in molds and the salting done by surface application. In making soft cheese the curd is not cut or pressed, but simply allowed to drain on a cloth or frame.

Reckoning that the fresh cheese which goes into the cheese room contains about 36 per cent of water, the products from 100 lbs. of normal milk will be as follows:—

Products from 100 Lbs. of Normal Milk.

	Total product	Water	Protein	Fat	Sugar	Ash
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Milk	100.0	87.10	3.40	3.90	4.85	7.5
Cheese	10.40	3.94	2.57	3.59	0.17	0.13
Whey	89.60	83.16	0.83	0.31	4.68	0.62

Ripening. Cheddar cheese ripens quickest at a moderately warm temperature, 50 to 60° F. being usually employed. It has been shown that it will also ripen at a much lower temperature—even at 30° F.—and the product will be of excellent quality. The time of ripening is necessarily longer when conducted at the lower temperature. During this curing process many complex changes occur. The sugar is converted to lactic acid, some water evaporates, and the insoluble proteins are partly converted into water soluble products. Ammonium compounds are also produced during the ripening process. Experiments have shown that fresh cheddar cheese contains but from 5 to 10 per cent of its protein in water soluble form, while at the end of 5 months, 35 to 40 per cent will be found in that form. These changes, according to one view, are produced primarily by the lactic acid organisms. Another theory ascribes them to enzymatic action, the enzymes being *galactase*, which is present in all milks and

possesses the power of peptonizing casein, and *pepsin*, contained in the rennet extract used. Whatever may be the cause of these changes, there can be no doubt that during the curing process the flavor and aroma are developed and that a considerable portion of the insoluble nitrogenous bodies are converted into water-soluble forms. The fat of cheese undergoes slight change during ripening, a small proportion of the neutral fat being decomposed and butyric and other fatty acids formed. The sugar which was present when the cheese was first made also disappears after a period of 7 to 10 days. Lactic acid is the main product formed from the sugar, although other products, probably of great importance to flavor development, are produced.

The ripening of special kinds of soft cheese, such as Roquefort and Camembert is attributed to such special ferments as molds, introduced during the process of manufacture. The average composition of various cheeses is given in the following table:—

Composition of Cheese.

	Water	Protein	Fat	Ash
	Per cent	Per cent	Per cent	Per cent
Cheddar.....	34.4	26.4	32.7	3.6
Cheshire	32.6	32.5	26.0	4.3
Swiss.....	35.8	24.4	37.4	2.4
Edam	36.3	24.1	30.3	4.9
Roquefort	31.2	27.6	33.2	6.0
Brie.....	50.4	17.2	25.1	5.4
Limburg	35.6	28.5	29.8	5.9

Under the United States pure food act, the following definitions of cheese were established.

(1) Whole milk or full cream cheese is cheese made from milk from which no portion of the fat has been removed.

(2) Skim milk cheese is cheese made from milk from which any portion of the fat has been removed.

(3) Cream cheese is cheese made from milk and cream or milk containing not less than 6 per cent of fat.

Standard. Whole milk or full cream cheese contains, in the water-free substance, not less than 50 per cent of butter fat.

The term "full cream" simply means that in the manufacture, whole milk has been used. It gives the impression that cream has been added, but such is not the case.

In some cases, cheese is adulterated by the addition of foreign fat, as lard. Such cheese is usually known as "filled" cheese.

Whey. As already stated, whey contains almost all of the milk sugar and albumin originally present in the milk, as well as a portion of the ash. The amount of fat in the whey will depend upon the treatment the curd has received. If the milk has been rich, the temperature of cooking high, and the curd roughly handled, considerable quantities of fat will be present. Where whey is rich in fat, it is customary to recover it for the manufacture of whey butter, either by allowing it to rise by gravity or through the use of the separator. The average composition of whey is about as follows: Water, 93.3 per cent; protein, 0.9; fat, 0.3; sugar, 4.9; ash, 0.6.

The cheese yield of milk. As has been seen, the two milk constituents that must determine the yield of cheese are casein and fat. The percentage of these varies in milks from different individual cows. They are not always in the same relation in two different milks. Milks of high fat content are not proportionately richer in casein than milks of low fat content. As a rule, for 100 pounds of fat in Jersey and Guernsey milk, one may expect 55 to 65 pounds of casein, while in the milk from the Ayrshire and Holstein breeds, there will be 65 to 75 pounds. There will be individual exceptions to this general statement.

In herd milks, although the relation of casein to fat is more constant, nevertheless variations in the proportion of these two constituents exist. The general rule that high fat milks do not yield in proportion to their fat, as much cheese as low fat milks, finds its explanation in the fact that high fat milks have proportionately less casein. This is illustrated in the following

table, which represents some work done by Babcock at a number of Wisconsin cheese factories.

Relation of Composition of Milk to Cheese Yield.

No. of groups	No. of reports	Range of fat	Average per cent of fat	Average yield of cheese per 100 lbs. milk	Lbs. of cured cheese for 1 lb. fat
1	24	Under 3.25	3.12	9.19	2.94
2	90	3.25-3.50	3.38	9.28	2.73
3	134	3.50-3.75	3.60	9.40	2.61
4	43	3.75-4.00	3.83	9.80	2.56
5	46	4.00-4.25	4.09	10.30	2.51
6	20	Over 4.25	4.44	10.70	2.40

It will be seen that the yield of cheese in proportion to the fat is less in the rich milks than in the poorer milks. A milk testing 6 per cent of fat will not make twice as much cheese as one testing 3 per cent.

Making out dividends at cheese factories. While the inequality of the cheese-yielding capacity of milks, and of the distribution of dividends, based on their fat content alone, has been recognized, it has been quite generally asserted that such inequality disappeared because of the improved quality of the product made from the milks of higher fat content. This is true when we consider cheese made from skimmed or partly skimmed milk and from milk very rich in fat or re-inforced with cream. But within the range of normal factory milk testing in fat from 3 to 4½ per cent, the quality of the product, as judged by buyers for the market, does not show uniform improvement with increase of fat in the milk. This has been shown by the work of the Canadian Experiment Station at Guelph and by the Wisconsin Station. No grading in the price of cheese, made from normal whole milk, based on its fat content, is at present practiced. Other factors, as the sanitary condition of the milk from which the cheese is made and the subsequent ripening processes, play an important part in determining the quality of the product.

Normal factory milks may vary in their cheese-yielding capacity, and the quality of the product from such milks is not determined by those variations that may occur in the fat and casein content. It is clear that the most complete and equitable method for the distribution of dividends at a cheese factory, is to allow for the amounts of both fat and casein delivered by the patron.

In its simplest form this consists in allowing equal values for both the fat and the casein, the amounts of which can be determined by methods applicable to factory conditions. Such tests are the Babcock fat test and the mechanical casein test devised by one of the authors. A patron delivering 100 pounds of milk, containing 3.5 per cent of fat, and 2.4 per cent of casein, should be paid on the basis of 5.9 pounds of cheese solids delivered. The price per pound of cheese solids would be determined by the price received for the cheese in the market.

CHAPTER XIII

INSECTICIDES AND RELATED SUBSTANCES.

A number of miscellaneous substances used in the agricultural industries depend primarily upon their chemical composition for effectiveness. Prominent among these substances are various preparations for the control or suppression of parasitic pests upon plants and animals and the restriction of contagious diseases. Brief consideration will be given here to the composition and action of the more important of these substances. For their practical applications, reference should be made to special books and bulletins on these subjects.

The following classification of these substances will be followed for the sake of order and convenience:—

- I. Insecticides.
- II. Fungicides.
- III. Disinfectants, deodorants and antiseptics.
- IV. Incidental materials.

Insecticides are substances used for destruction of insects feeding upon the fruit, foliage or bark of vegetation and for the removal of ticks and similar pests from animals. These materials have won general recognition as essential factors in the production of high grade fruit.

They may be classed as stomachic, contact, or gaseous poisons, according to their mode of action. Such insects as the codling moth of the apple and the "potato bug," which are surface feeders, may be reached by poisons of the first class; the aphides or plant lice and other sucking insects must be attacked by poisons of the second class; and the resistant scale insects and other pests are most efficiently destroyed by fumigation with a poisonous gas.

Stomachic poisons for insects are generally dependent upon arsenic for their poisonous effects. Arsenic does not enter these

substances as the free element, but as a constituent of "white arsenic," technically called "arsenious oxide" or "arsenious acid." Soluble compounds of arsenic were at first tested as insecticides, but they were found to cause serious injury to foliage. Later experiments have demonstrated that arsenical compounds insoluble in water produced the desired effect, probably by virtue of the solvent action of the juices of the digestive tract of the insect. The resulting effort to furnish the arsenic of insecticides in insoluble form has been stimulated also by the passage of state laws restricting the amount of arsenic permissible in soluble form.

Paris green has been a leading insecticide in America for fifty years. It was first used, apparently, in an attempt to control the Colorado beetle or "potato bug" which had made its appearance in the western United States. This stomachic poison contains arsenious acid, acetic acid and copper in a definite chemical structure known as "Schweinfurt's green," and technically known as "copper aceto-arsenite." It is prepared by adding a hot solution of arsenious oxide to a hot solution of copper acetate. Paris green separates from the mixture and settles out as a rather fine powder of a clear, green color. The pure compound is practically insoluble in water, but readily soluble in ammonium hydroxide, or ammonia water, and has the following composition:

	<i>Per cent</i>
Copper oxide.....	31.29
Arsenious acid.....	58.65
Acetic acid.....	10.06

Scorching of foliage by applications of Paris green suspended in water was frequently observed during its early use. Gillette showed, in 1890, that the use of lime water or Bordeaux mixture with Paris green prevented this injury. A year later, Kilgore found that the scorching effects were due to soluble forms of arsenic and concluded that the preventive substances acted by virtue of their lime, which fixed the soluble arsenic in insoluble compounds. Experiments at the New York Experiment Station with Paris green and sodium arsenite applied to potatoes led to

the conclusions: "That Paris green is not injurious to potato foliage if applied in moderate quantity with lime water or Bordeaux mixture evenly distributed;" and "That sodium arsenite should not be applied to potatoes except with Bordeaux mixture."

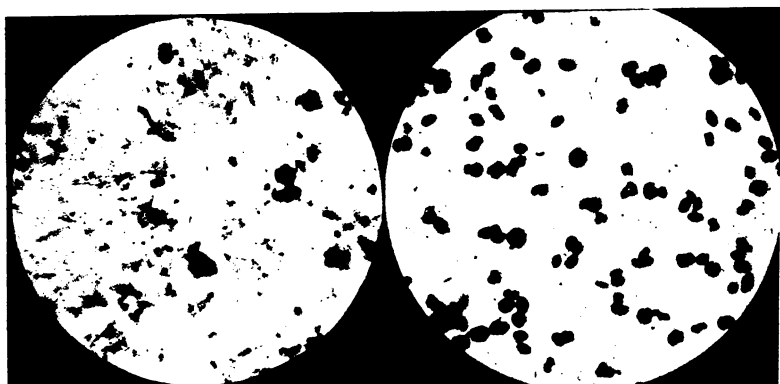
Adulteration and the manufacture of impure Paris green were more or less prevalent previous to the passage of insecticide laws. Gypsum or sulphate of lime was one of the most common adulterants. This has little if any insecticidal value and was added to increase the bulk. Other impurities may result from the use of crude materials or careless methods in preparation. Woodworth has given some simple tests to detect common forms of adulteration.

The ammonia test is performed by taking an amount of Paris green that can be held on a five cent piece, transferring it to a drinking glass and adding about six tablespoonfuls of household ammonia or "spirits of hartshorn." Keep the contents of the glass well stirred for five minutes. If the "green" is pure, it will then form a clear, dark-blue solution and leave no solid residue. If gypsum is present, it will form a white suspension in the liquid and finally settle to the bottom of the glass. This is not a conclusive test since impurities soluble in ammonia may be present.

The glass test often enables one to distinguish adulterated samples not detectable by ammonia. Take such an amount of Paris green as can be picked up readily on the point of a pen knife and place it on a small rectangular piece of clear glass. Holding the glass in an inclined position, gently tap the lower edge and the Paris green will move down the inclined plane leaving a track of dust behind. In the case of a pure "green," the dust will be of a bright green color. If the sample is impure, it may leave a white, pale-green or other-colored streak, depending upon the color of the adulterating substance. This test is best used for comparing unknown samples with a sample known to be pure. Like the ammonia test, it is not infallible. **Varia-**

tions in the color of samples in bulk, especially an abnormally pale shade, and a tendency to dampness or lumping, indicate almost certain adulteration.

Microscopic examination offers the most certain and satisfactory of simple methods for testing the purity of Paris green. The sample is prepared for this test as in the "glass test" just described and the dust is then examined under a medium power objective. The Paris green will be seen in the form of clean



On the right—pure Paris-green; on the left—adulterated Paris-green.

round balls; and in perfectly pure samples these are all that can be seen. Impure samples will exhibit also a considerable quantity of material of crystalline or irregular shapes, and usually white in color. Excess of free arsenious oxide is not so readily distinguished by this test. When mixed with the prepared Paris green it is as easily recognized by the microscope as is any other form of adulterant, but when added in the process of making, it adheres firmly to the particles of true green and causes them to stick together in clusters.

Chemical analysis is the only absolute means of determining the purity of this insecticide. One of the most important of the chemical determinations, is that for estimating the soluble arsenic in Paris green and other insecticides. Two procedures are

in use. In one case the sample is extracted with a hot 33 per cent solution of sodium acetate, while in the other case it is extracted for several days with cold water and the amount of arsenic in solution estimated. The former method apparently shows more nearly the amount of soluble arsenic that may be present, while the latter treatment more nearly simulates conditions to which the insecticide is exposed in the field.

Control laws have been passed by some states to regulate the composition and sale of insecticides as has been done in the case of commercial fertilizers and feeding stuffs. In some cases, special stipulation is made with regard to the amount of free arsenious oxide permissible in Paris green. Idaho allows a maximum amount of six per cent for this constituent and California allows but four per cent.

Green arsenoid is the trade name for a compound resembling Paris green in composition and effects. It contains no acetic acid but is formed from copper oxide and arsenious oxide, and is technically known as copper arsenite. The pure compound contains about 53 per cent of arsenious oxide. Sodium sulphate or Glauber's salt is a by-product in the process of preparation and may occur together with sand and other impurities in such an insecticide; they should, however, be present in only small amounts. The following data from an analysis of green arsenoid illustrates the relative effect of sodium acetate solution and cold water upon the arsenic of insecticides:

Free arsenious acid	Per cent
(extracted with sodium acetate).....	3 23
(extracted with cold water).....	5.88

This insecticide has given excellent results when mixed with lime to "bind" the soluble arsenious oxide.

London purple was imported from England by Bessey in 1878 as a substitute for Paris green in destroying the potato beetle. It is prepared by boiling a purple residue from the dye industry, containing free arsenious acid, with slaked lime. Calcium arsenite is formed at first, but by subsequent boiling and exposure

to the air, this may be partly oxidized to calcium arsenate. This insecticide carries some impurities brought over from the dye-making process, and as a result of insufficient addition of lime or incomplete boiling some of the arsenious acid may be present in free condition. Haywood examined four samples with the following results:

	<i>Per cent</i>
Moisture	1.87-4.07
Sand	2.46-3.55
Arsenious acid, total	6.40-17.31
Arsenic acid, total	26.50-35.62
Arsenious acid, soluble in cold water	1.44-13.49
Arsenic acid, soluble in cold water	7.12-19.56
Lime	23.59-25.09

Water decomposes both calcium arsenate and calcium arsenite to some extent and consequently a solubility determination with water does not show how much arsenious acid was actually free. These soluble arsenic salts are probably less objectionable than free arsenious acid, although it is recognized that London purple is more injurious to foliage than is Paris green and common arsenic (arsenious oxide) is more harmful than either. This condition may be corrected by adding lime to the London purple when suspending it in water for application to foliage. Since it is subject to considerable variation in composition this insecticide should be bought on guarantee of purity.

Calcium arsenite was proposed by Kilgore as an insecticide, following his observations with Paris green. This can be made by boiling one pound of arsenious oxide and two pounds of lime in water and diluting for use. Since this compound has been shown to form about 75 per cent of London purple, it is probably more economical to use the latter insecticide.

Arsenite of soda is prepared by boiling arsenious oxide with four times its weight of sodium carbonate. The injurious effects of this compound upon potato foliage have been referred to. Similar results were produced in trials of sodium arsenate against the gypsy moth in Massachusetts.

"Dips" which have proved very efficient in destroying sheep ticks have given sodium arsenite recognition as a valuable insecticide. The following formula has been used with success:

Arsenite of soda	5 pounds
Soft soap	5 pounds
Aloes	12 ounces
Water	100 gallons

The soap is said to increase the retention of the dip on the fleece and aloes renders it distasteful to the animal and prevents poisoning. Sodium *arsenate* has been used against locusts by adding it to sugared water and spraying the grass in the infested region.

Lead arsenate was recommended as an insecticide in 1892 and was first used against tent caterpillars. It is prepared by adding lead acetate to sodium arsenate in water. These substances dissolve readily in the cold and react to form sodium acetate and lead arsenate, the latter remaining suspended as a fine white powder. This insecticide should be handled in the form of a paste, for once dried it is suspended with difficulty. Recent experiments show that lead nitrate is to be preferred to the acetate in making the arsenate because the product remains in suspension better and contains more lead-hydrogen-arsenate, carrying a higher percentage of arsenic than is the case with preparations from the acetate. This is apparently the most insoluble of all the arsenical insecticides and least likely to scorch the foliage. Headden has shown, however, that care should be taken to use pure water in the preparation of even this spraying mixture. Solutions of 0.1 per cent sodium sulphate or 0.05 per cent common salt dissolve considerable amounts of arsenic from lead arsenate. Practical spraying tests with lead arsenate in distilled water showed that sodium carbonate or sodium chloride at the rate of 10 grains per gallon in the spray fluid produced severe injury and 40 grains of the latter salt per gallon injured about 50 per cent of the foliage. Salt waters and alkali surface waters must therefore be avoided.

Haywood gives the following directions for preparing lead arsenate; for each pound of lead arsenate to be made, use—

	Ounces
Formula A. Sodium arsenate (65 per cent).....	8
Lead acetate (sugar of lead).....	22
Formula B. Sodium arsenate (65 per cent).....	8
Lead nitrate.....	18

Dissolve each salt separately in 1 to 2 gallons of water, using wooden vessels. When dissolved, pour the lead solution into the sodium arsenate, stirring thoroughly until the mixture just turns a potassium-iodide test paper to a bright yellow. The lead salt is then in slight excess. A large excess should be avoided. Allow the lead arsenate to settle, and pour off the liquid. These chemicals are extremely poisonous and should be plainly labeled and handled with care.

Pink arsenoid is a commercial preparation made by adding lead acetate to sodium arsenite and coloring the insoluble product with a dye. It is composed chiefly of lead arsenite, only a small proportion of the arsenic being soluble, and has given satisfactory results.

White arsenoid was the product of an attempt to put barium arsenite upon the market as an insecticide. Contrary to expectation, all the arsenious oxide of this preparation was found to be soluble in cold water. It gave poor results and was short-lived.

White arsenic, or the simple arsenious oxide, has been used as a constituent of "dips" and various insect and animal poisons. It is volatile at a comparatively low heat and mixed with sulphur, it has been successfully used against ants by forcing the vapors into the nest.

Arsenical poisoning may occur in the case of trees heavily sprayed with arsenical insecticides. Headden found arsenic in diseased fruit trees and this condition was correlated with an accumulation of arsenic in the soil in compounds from which it was rendered gradually soluble by the salts of the soil solution.

Paige found, in connection with reported poisonings associated with combating the gypsy moth, that the amount of lead arsenate consumed by herbivora with the grass from beneath sprayed trees might lead to serious results. These findings emphasize the need of care in the use of poisonous spraying mixtures.

Hellebore, from the root of the pokeroor plant, and *Pyrethrum* or insect powder, from the flower heads of certain plants, have poisonous insecticidal properties attributed to alkaloids. Both deteriorate with age.

Purity and efficiency of insecticides can only be insured by purchasing them under guarantee or under recommendations from reliable authorities, such as the state experiment stations, or by the purchase of simple constituents to be combined by the purchaser.

Contact poisons may act by their caustic properties and by absorption from the surface of the insect, or by closing the tracheae or breathing tubes. These will now receive our consideration.

Lime-sulphur wash is typical of the former class of insecticides. It was used in California as a sheep dip, where it was first applied also to the San José scale in 1886. The wash was prepared by boiling sulphur and slaked lime in equal parts, which produced first a simple sulphide of lime (CaS) of a white color. Prolonged boiling causes the color of the wash to pass through shades of yellow to a deep orange color with the formation of poly-sulphides of lime carrying increasing proportions of sulphur. The chemistry of lime-sulphur wash has been investigated at the New York Experiment Station. The chief compounds were found to be calcium penta-sulphide (CaS_5), calcium tetra-sulphide (CaS_4) and calcium thiosulphate (CaS_2O_3). Boiling converts the last-named compound into calcium sulphite and free sulphur, and the calcium sulphite then oxidizes by exposure to the air into calcium sulphate.

The specific gravity of the wash and the amount of calcium and sulphur in solution increased with the amount of lime used.

The higher amounts of lime produced more calcium tetra-sulphide, while with the smaller amounts, the mixture was more nearly penta-sulphide. The largest amount of soluble sulphides was formed by boiling about one hour, especially when the largest amount of lime was used. The amount of sediment increased with increased boiling, due to the formation of calcium sulphite. It was found that the addition of extra lime to the diluted lime-sulphur solution might seriously decrease its insecticidal value as a result of the decomposition of the higher sulphides of calcium with formation of free sulphur. Where pure lime was used, the sediment, found to consist of calcium sulphite, free sulphur and hydroxide and carbonate of lime, formed suitable material to add in the making of a new wash. It was also found that magnesium oxide when present in the lime, as in dolomitic limestone, tended to decompose the sulphides of calcium with evolution of hydrogen sulphide. The importance of pure lime for this insecticide is thus emphasized. An examination of commercial lime-sulphur preparations revealed great variations in composition. Since field experiments have demonstrated that this insecticide derives its chief value from the soluble lime-sulphur compounds, commercial preparations should be bought on the basis of the strength and composition of their supernatant liquid.

Stewart states that the problem of making concentrated lime-sulphur solutions is essentially one of preventing crystallization and securing a storable product of high density. He finds that the formation of crystals is largely due to an excess of lime and exposure to the air when cold. Exposure to the air may be avoided by covering the surface of the wash with oil. Arsenite of lime, as a supplementary insecticide, has been found to produce least decomposition of the sulphur compounds of this wash.

Haywood found that a one hour period of boiling dissolved practically all the sulphur used for this wash. The addition of common salt was found to have no effect so far as the sulphur compounds of the wash were concerned.

On theoretical grounds, Haywood recommends the following formula for preparing, at minimum cost, a wash with the maximum amount of sulphur in solution and a moderate excess of lime:

Lime	20-22½ pounds
Sulphur	20 pounds
Water	50 gallons

The mixture is best when boiled by passing steam through it. Moderate slaking of the lime was found to have no influence, but a comparison of flowers of sulphur and crystallized sulphur showed that the crystalline form, even when finely ground, required much longer boiling for maximum solution and gave a product of variable composition, apparently dependent on the size of the particles.

To determine what changes take place after the wash is applied to trees, measured quantities of the clear liquid were absorbed on filter papers and dried in the open air exposed to sunlight. Analyses at successive stages showed the gradual oxidation of calcium penta-sulphide into calcium thiosulphate, calcium sulphite and finally calcium sulphate, with deposition of free sulphur. Wetting the paper daily to simulate the daily wetting of branches by dew greatly increased the rapidity of the process. Indications were, that after four to six months only free sulphur and calcium sulphate would be left. Haywood believes that the excess of caustic lime loosens the scale insects from the tree, and that the active agents in killing are sulphur in finely divided form, thiosulphate, for a time, and sulphite, which is gradually formed by the slow oxidations.

Self boiled washes, in which the heat for solution is produced by the chemical reaction incident to slaking the lime, are unsatisfactory, even when a maximum amount of heat is so generated.

Lime, sulphur, salt, soda-wash, in which caustic soda is used in addition to lime, has nearly the same composition and action as the simpler wash already described. It is less effective, how-

ever, because it decomposes more slowly and the sodium sulphite formed is more subject to loss by washing than is calcium sulphite.

Kerosene has been used as a contact insecticide against scale insects. It is applied as a spray to the dormant trees, but is frequently injurious. Applied to stagnant pools, it effectually suffocates the emerging pupae of mosquitoes; and in the "hopper-dozer" it destroys grasshoppers which are trapped in it, by forming an oil film over the tracheae.

Kerowater sprays were the result of attempts to dilute kerosene before applying it to trees. Kerosene is not miscible with water but by forcibly mixing these liquids at the nozzle of the spray pump the kerosene was temporarily diluted.

Kerosene emulsions are comparatively permanent suspensions made by mixing kerosene oil with soap solutions. They are not true solutions, for the oil can be observed under a microscope as droplets suspended in the soap solution. Well made emulsions persist for several hours, and even for days, and facilitate an even distribution of the kerosene. Crude petroleum oils, which are closely related to kerosene but less volatile than the latter, have taken its place to a great extent because of the greater efficiency and safety attendant upon their use.

Miscible oils are preparations of this nature. They are based on a standard soap solution with which various proportions of different oils are emulsified. Crude oil, a mixture of petroleum oils heavier than kerosene; paraffin oil, a lubricating oil from petroleum; and resin oil, from the distillation of resin, are used. The crude oils are efficient in $6\frac{2}{3}$ per cent strengths, whereas kerosene is inefficient below 20 per cent strength.

Penny gives the following formula for a standard miscible oil:

The "Soap Solution."

Menhaden oil	10 gallons
Carbolic acid	8 "
Caustic potash	15 "
Heat to 290° or 300° F., then add kerosene	2 "
Water	2 "

From the above soap solution, the miscible oil is prepared according to the following formula:

Soap solution.....	3½ gallons
Paraffine oil.....	40 "
Rosin oil.....	6 "
Water, as required by test.	

In the process of making the soap solution the kerosene should be added while the soap is hot. The heavier oils should be stirred into the soap solution at moderate temperatures. Freezing temperatures should be avoided. The amount of water to be added is a matter of experiment but it should be used in quantity sufficient to produce an emulsion of creamy consistency. One gallon of the soap solution or emulsifier will make 8 to 14 gallons of miscible oil and these 8 to 14 gallons will make from 100 to 210 gallons of spray material, according to dilution.

Resin soaps, efficient against orange scale insects, are prepared by boiling resin with carbonate of soda and diluting the solid product with water.

Fish oil soap and **whale oil soap**, prepared by boiling the oils in potash lye and diluting with water, are effective against plant and animal lice, but the commercial preparations are subject to great variations in composition.

Tobacco decoction depends for its value upon the poisonous properties of nicotine. This alkaloid is soluble in water, and hot water extractions of the stalk and waste of tobacco are used as an insecticide.

Gaseous insecticides are used against insects particularly difficult to attack. Hydrocyanic acid gas is by far the most effective substance in this class. It is produced from:—

Potassium cyanide, pure.....	1 ounce
Sulphuric acid, commercial.....	2 "
Water.....	4 "

This is the quantity recommended for each 100 cubic feet of space. The cyanide should be added last, having the mixture in

an earthen-ware vessel. Potassium sulphate is formed and the poisonous hydrocyanic acid is rapidly liberated as an invisible gas. This is an extremely powerful poison, a single breath being fatal, and by no means should it be inhaled by the operator. To retain the gas and secure efficient action, it should be applied in tightly closed rooms or buildings, or in tents specifically provided for the purpose, allowing it to act for an hour or more. The enclosure should then be opened from the outside and thoroughly aired before being entered, and the strongly acid residue from the reaction should be carefully disposed of.

Carbon bisulphide is a colorless, volatile liquid formed by passing sulphur vapors over red hot charcoal. The gas evolved from the liquid is heavier than air, inflammable and fatal to insects breathing it. Its chief use is for the destruction of weevils in grain. One teaspoonful for each cubic foot of space should be placed in a shallow dish at the surface of the grain, and one hour allowed for the evaporation of each teaspoonful used. The heavy vapors sink through the grain to the bottom of the bin, where they may be released by boring holes through the wall. Ants, moles, prairie dogs and similar pests are exterminated by placing cotton saturated with carbon bisulphide in the heaps or runs and covering tightly. Carbon bisulphide should never be brought near flames.

Fungicides are materials utilized for the destruction of parasitic plants. Hyposulphite of soda, lime-sulphur and sulphur alone were used in this capacity as early as 1885 against apple scab and leaf blight.

Bordeaux mixture has been the premier fungicide since 1883, when Millardet used it against the downy mildew of the grape. It was accidentally discovered by observing the flourishing condition of vines to which lime and copper salts had been applied to prevent the theft of grapes in the province of Bordeaux, France. Several formulæ have been superseded generally by

the so-called "normal" formula, or 1.6 per cent Bordeaux, which consists of:

Copper sulphate.....	6 lbs.
Quick lime	4 lbs.
Water	50 gallons

The lime should be slightly in excess. This may be accomplished by weighing the pure salts for the mixture, or by testing the product.



Note the beneficial results from the control of potato diseases by Bordeaux mixture.

The litmus test depends upon the fact that so long as copper sulphate is in excess blue litmus will be turned red when moistened with the Bordeaux mixture. Enough lime should be present so that red litmus is turned blue.

The ferro-cyanide test may be used also for this purpose. A teaspoonful of the clear liquid, obtained by straining if necessary, should be added to a few drops of potassium-ferrocyanide solu-

tion in a white porcelain dish. A reddish brown precipitate or color indicates the presence of soluble copper salts, and lime should be added to the mixture until this no longer appears.

The fungicidal properties of Bordeaux mixture are chiefly due to the insoluble compounds formed and it is important to keep these thoroughly in suspension. To facilitate this, the copper sulphate and lime should be dissolved separately, each in one-half the water, and when the lime is cool, they should be poured together with constant stirring. In this way, the dilute solutions react to form a fine suspension which will not settle for several hours. The chemistry of Bordeaux mixture has not been thoroughly investigated. According to Lodeman, when the copper sulphate is just neutralized, most of the copper is probably precipitated as a hydrate; but excess of lime added to a concentrated "mixture" forms another compound which may be a basic sulphate of copper and lime.

Soda Bordeaux, made with caustic soda in place of lime in the regular formula, has given satisfactory results.

Copper ammonium sulphate, a clear blue solution formed from copper sulphate and ammonia, also called "eau celeste," has been applied as a fungicide, but its caustic action renders it unsafe. Copper carbonate dissolved in ammonia, however, has given good results. It should be freshly prepared, as the ammonia may volatilize on standing, causing the copper to fall out of solution.

Copper sulphate has been applied to dormant trees and greenhouse plants as a dilute solution, but it possesses a strongly acid reaction and should be used with care. Smut on grains is destroyed by this fungicide. A one to two hour immersion of oats in a 0.5 to 1.0 per cent solution may be safely practiced, but stronger applications retard germination.

Potassium sulphide is used against mildews at the rate of one-half ounce to one gallon of water. Strong solutions are destructive to plants. Potash lye and formaldehyde-glycerine

mixture, properly diluted, have proved valuable fungicides under certain conditions.

Formalin or formaldehyde, is a most efficient agent for destroying smut spores on grain. The seed should be immersed for ten minutes in a solution of 1 pint of "40 per cent" formalin to 20 gallons of water. Stronger solutions have been found injurious to the germinating power of barley. The seed should be spread and finally mixed so as to dry with not more than two to three hours contact with the formalin.

Disinfectants are substances which accomplish the total destruction of the germs of infectious diseases. They may also act as deodorants or destroyers of foul odors.

Antiseptics prevent decomposition or putrefaction by arresting the development of germs, but do not necessarily destroy them. Disinfectants in weak solutions may act as antiseptics. Refrigeration, common salt and sugar, all of which are largely used in preserving fruits, meats, etc., are good examples of antiseptics.

Formaldehyde is perhaps the most commonly used chemical disinfectant. It is a product of the oxidation of wood alcohol and is put upon the market in a 38 to 40 per cent solution in water. A five per cent solution made from this should be mixed with any solid matter to be disinfected. Gaseous formaldehyde is used for disinfecting inclosed space and porous solid matter in bulk. The gas should be delivered into a tightly closed compartment in one of the following ways: Formalin may be heated under pressure or in a simple retort and the gas piped into the space; formalin may be sprayed upon sheets or other extensive surfaces in the space to be disinfected and the gas liberated by simple evaporation; six parts of formalin may be poured upon five parts by weight of chemically pure potassium permanganate. In the last case, heat is generated by chemical reaction and 50 per cent of the formaldehyde is liberated as a gas. Ten ounces of formalin are necessary for each 1000 cubic

feet of space in the first two cases and twice as much must be used in the permanganate method. This disinfectant also acts as a deodorant.

Paraform is a condensed form of formaldehyde put up as a powder or as pastils. Two ounces of paraform liberate gas sufficient to disinfect 1000 cubic feet of space.

Mercuric chloride or corrosive sublimate is a poisonous, white, crystalline salt. It is usually put up in tablet form with ammonium chloride to facilitate dissolving in water. Strengths of 1 to 500 to 1 to 1000 are used, the greater strength being necessary to destroy bacterial spores. This is a powerful stomachic poisoning and must be handled with care. It forms insoluble compounds with proteins and hence raw eggs and milk are given as antidotes. On account of its chemical affinity for proteins, unless liberally used it has little disinfecting power when applied to excreta, blood and similar protein containing materials. Solutions of this salt should be used only in glass or earthen ware, as it reacts with tin and other common metals.

Chloride of lime (bleaching powder) is both a disinfectant and deodorizer. It is prepared by passing chlorine gas over slaked lime. The compound decomposes rapidly on exposure to the air and hence is put up in hermetically sealed containers and is reliable only when freshly removed from these.

Carbolic acid is a derivative of benzene, a hydrocarbon which forms the basis of the coal tar dyes. At ordinary temperatures it has the crystalline form of long, white needles. One part of water to 9 parts of the crystals produces a liquid, in which form it is commonly dispensed. By dissolving in warm water a solution of slightly over 6 per cent carbolic acid can be made. This is used as a spray and wash. *Crude carbolic acid* is a crude preparation from coal tar distillation, the latter substance being the liquid by-product in the production of gas and coke from coal. This disinfectant is a mixture of various coal tar oils and so-called "cresylic acid," and contains little or no true carbolic acid. The disinfecting power is due to cresols of the "cresylic

acid," bodies related to carbolic acid. Therefore the "cresylic acid" content of the crude material should be known and from this a 2 per cent solution of the constituent made. The undissolved cresols that are present necessitate a thorough mixing while spraying in order to facilitate an even distribution of the material.

Cresol (trikresol) is supplied to the trade from the coal tar industry in varying degrees of purity. It contains bodies of the same general composition, but which are superior to carbolic acid as disinfectants. Grades containing less than 90 per cent of "cresylic acid" (cresols) are undesirable because of the suppression of solubility of the cresols by the oils usually present as impurities. A 2 per cent cresol solution is considered superior to a 5 per cent solution of carbolic acid.

Liquid carbolic acid is a mixture of cresols, usually 90 to 98 per cent pure, which should be bought on guaranteed content of "cresylic acid." *Compound solution of cresol* is a mixture of equal parts of cresol and linseed-oil-potash soap. It is applied like cresol with the added advantage of greater solubility in water.

These coal tar compounds are the basis also of a number of commercial, soluble disinfectants and dips, such as creolin, lysol, solveol, Car-Sul dip, carboleum, cresol, disinfectall, germol, and zenoleum. Fly removers, applied to animals for protection against flies, have been prepared from these substances. Light coal tar oil for this purpose has given the most satisfaction as to persistence and freedom from gumming on the animal's coat.

Creosote preparations for antiseptic treatment of timbers against bacteria and fungi are the heavier fractions of coal tar oil and carry carbolic acid, the cresols, naphthalene, (also used in moth balls), anthracene, and similar high-boiling hydrocarbons and carbolic-acid-like bodies.

Deodorants include some of the above materials, such as chloride of lime, which destroy the causal substance through chemical action. Other substances merely cover up the offensive

odor by the odor they themselves produce Charcoal is a deodorant by virtue of its great absorptive capacity for gases. It acts by mechanical absorption of offensive gases into its pores.

Incidental materials. Use is often made of arsenite of soda, common salt, carbolic acid, sulphuric acid and other compounds, as weed destroyers. Iron sulphate solution, prepared by dissolving 100 pounds of the granulated salt in 50 gallons of water for each acre of land has been successfully used in eradicating wild mustard. Untoward effects of these substances on the soil can be corrected in many cases by applications of lime. Copper sulphate applied to reservoirs at the rate of one part of salt to from one million to ten million parts of water has been extensively used in destroying algae growth.



APPENDIX

COMPOSITION OF SOILS.

Snyder gives the following average composition of 200 fertile soils; analysis was made by strong hydrochloric acid.

Insoluble matter.....	79.95	Per cent.
Potash.....	0.29	" "
Soda.....	0.25	" "
Lime.....	2.16	" "
Magnesia.....	0.55	" "
Iron oxide.....	2.68	" "
Alumina.....	5.20	" "
Phosphor acid.....	0.24	" "
Sulphur trioxide.....	0.03	" "
Carbone dioxide.....	1.12	" "
Volatile matter.....	7.00	" "
	99.47	
Volatile matter containing:		
Humus.....	3.35	" "
Nitrogen.....	.29	" "

Fertilizing Constituents in One Ton of Material.

Feed	Nitrogen lbs.	Phosphoric acid, lbs.	Potash lbs.	Dry matter lbs.
Concentrates				
Corn	36.4	14.0	8.0	1,764
Corn bran.....	32.6	24.2	13.6	1,818
Hominy chops.....	32.6	19.6	9.8	
Gluten feed.....	76.8	8.2	0.6	1,844
Wheat.....	47.2	15.8	10.0	1,732
Wheat middlings.....	52.6	19.0	12.6	1,748
Rye.....	35.2	16.4	10.8	1,714
Barley.....	30.2	15.8	9.6	1,714
Malt sprouts.....	71.0	28.6	32.6	1,760
Brewers' grains (dried).....	72.4	20.6	1.8	1,810
Oat feed.....	34.4	18.2	10.6	1,734
Cotton seed meal.....	13.5	57.6	17.4	1,823
Peas.....	61.6	16.4	19.8	1,720
Roughage				
Corn stover.....	20.8	5.8	28.0	1,816
Timothy hay.....	25.2	10.6	18.0	1,726
Red clover hay (medium).....	41.4	7.6	44.0	1,684
Red clover hay (mammoth)....	44.6	11.0	24.4	1,772
Crimson clover hay.....	41.0	8.0	26.2	1,672
Alfalfa hay.....	43.8	10.2	33.6	1,850
Silage				
Corn.....	5.6	2.2	7.4	441
Straw				
Oat.....	12.4	4.0	24.8	1,710
Barley.....	26.2	6.0	41.8	1,716
Roots and Tubers				
Potatoes.....	6.4	2.4	9.2	500
Beet, common.....	4.8	1.8	8.8	245
Beet, sugar.....	4.4	2.0	9.6	360
Rutabaga.....	3.8	2.4	9.8	218
Turnip.....	3.6	2.0	7.8	184
Miscellaneous				
Cabbage.....	7.6	2.2	8.6	220
Rape.....	9.0	3.0	7.2	290

COMPOSITION OF FERTILIZERS.

Composition of fertilizer materials supplying nitrogen.

	Per cent Nitrogen	Per cent Phosphoric acid	Per cent Potash
Nitrate of soda.....	15.5-16	.....	.....
Sulphate of ammonia.....	19 -20.5	.....	.....
Dried blood (high grade).....	12 -14	.....	.....
Concentrated tankage.....	11 -12.5	1 - 2	.....
Tankage (bone).....	5 - 6	11 - 14	.....
Nitrogenous guano.....	3 - 7	9 - 19	2 - 4

Composition of fertilizing materials supplying phosphoric acid.

	Per cent Phosphoric acid	Per cent Nitrogen
S. Carolina rock (ground) (floats).....	25 - 30	.....
S. Carolina rock (dissolved).....	12 - 16	.....
Florida rock.....	25 - 30	.....
Thomas slag.....	18 - 23	.....
Ground bone.....	20 - 25	2.5 - 4.5
Steamed bone.....	22 - 29	1.5 - 2.5
Bone black.....	32 - 36	.....

Composition of fertilizer materials supplying potash.

	Per cent Potash	Per cent Nitrogen	Per cent Phosphoric acid
Muriate of potash (80-85 per cent pure)....	50 - 53	.....	.....
Sulphate of potash (high grade).....	48 - 52	.....	.....
Sulphate of potash (low grade).....	28 - 30	.....	.....
Kainit.....	12 - 13	.....	.....
Tobacco stems.....	3 - 8	2 - 3	3 - 5
Wood ashes.....	4 - 8	.....	1 - 2

COMPOSITION OF FEEDING STUFFS.

The following brief table gives the composition of some typical feeding materials (taken from "The Feeding of Animals," Jordan, Appendix):

	Water per cent	Ash per cent	Crude Protein per cent	Crude Fiber per cent	Nitrogen-free extract per cent	Ether extract per cent
FODDERS						
Corn fodder (green).....	79.3	1.2	1.8	5.0	12.2	.5
" " (field cured).....	42.2	2.7	4.5	14.3	34.7	1.6
Corn silage.....	79.1	1.4	1.7	6.0	11.0	.8
Timothy (green).....	61.6	2.1	3.1	11.8	20.2	1.2
" hay.....	13.2	4.4	5.9	29.0	45.0	2.5
Alfalfa (green).....	71.8	2.7	4.8	7.4	12.3	1.0
" hay.....	8.4	7.4	14.3	25.0	42.7	2.2
Clover hay (red).....	15.3	6.2	12.3	24.8	38.1	3.3
Roots						
Turnips.....	90.5	.8	1.1	1.2	6.2	.2
Rutabagas.....	88.6	1.2	1.2	1.3	7.5	.2
GRAINS						
Corn.....	10.9	1.5	10.5	2.1	69.6	5.4
Barley.....	10.9	2.4	12.4	2.7	69.8	1.8
Oats.....	11.	3.	11.8	9.5	59.7	5.
Wheat.....	10.5	1.8	11.9	1.8	71.9	2.1
MILL PRODUCTS						
Corn meal.....	15.	1.4	9.2	1.9	68.7	3.8
Corn-and-cob meal.....	15.1	1.5	8.5	6.6	64.8	3.5
Wheat flour.....	12.4	.5	10.8	.2	75.	1.1
Wheat bran.....	11.9	5.8	15.4	9.0	53.9	4.0
Gluten feed.....	7.8	1.1	24.0	5.3	51.2	10.6
Oat feed.....	7.7	3.7	16.0	6.1	59.4	7.1
Brewers' grains (dried).....	8.2	3.6	19.9	11.	51.7	5.6
Linseed meal (new process)....	10.0	5.2	36.1	8.4	36.7	3.6
Malt sprouts.....	5.0	6.4	27.6	10.9	47.1	3.0

AVERAGE COEFFICIENTS OF DIGESTIBILITY.

A brief table giving the coefficients of digestibility of important feeding materials. Taken from the "Feeding of Animals" (Jordan).

Digestion by Ruminants.

Feed	Dry matter per cent	Organic matter per cent	Ash per cent	Crude protein per cent	Fiber per cent	Nitrogen-free extract per cent	Ether extract per cent
FODDERS.							
Corn fodder (green)....	67.8	69.8	35.6	59.7	60.2	73.7	74.1
" " (field cured)	68.2	70.7	30.6	56.1	65.8	72.7	73.9
Corn silage.....	70.8	73.6	30.3	56.0	70.0	76.1	82.4
Timothy (green).....	63.5	65.6	32.2	48.1	55.6	65.7	53.1
" hay.....	56.6	57.9	32.8	46.9	52.5	62.3	52.2
Alfalfa (green).....	67.0	64.0	.....	81.0	41.0	72.0	45.0
" hay.....	58.9	60.7	39.5	72.0	46.0	69.2	51.0
ROOTS.							
Turnips.....	92.8	96.1	58.6	89.7	103.0	96.5	87.5
Rutabagas.....	87.2	91.1	31.2	80.3	74.2	94.7	84.2
GRAINS.							
Corn.....	89.4	89.6	.....	67.9	58.0	94.6	92.1
Barley.....	.....	86.0	.....	70.0	50.0	92.0	89.0
Oat.....	.....	71.0	.....	78.0	26.0	77.0	83.0
MILL PRODUCTS.							
Corn meal.....	89.4	89.6	.....	67.9	.....	94.6	92.1
Corn and cob meal.....	78.7	79.8	.....	55.6	45.7	87.6	84.1
Wheat bran.....	62.3	65.7	.....	77.8	28.6	69.4	68.0
Gluten feed.....	86.3	87.3	.....	85.6	78.0	89.2	84.4
Oat feed.....	62.0	65.3	.....	81.1	42.6	67.4	89.0
Brewers' grains (dried)...	61.6	65.4	.....	79.3	52.6	57.8	91.1
Linseed meal (new process).....	79.2	81.8	.....	85.2	80.4	86.1	96.6
Malt sprouts.....	67.1	67.2	.....	80.2	32.9	68.1	104.6

Digestion by Horses.

Timothy (hay).....	43.5	44.1	34.0	21.2	42.6	47.3	47.3
Alfalfa (hay).....	.....	58.0	.....	73.0	40.0	70.0	14.0
Oat (grain).....	.....	69.0	.....	79.0	29.0	75.0	71.0
Barley ".....	.....	87.0	.....	80.0	.....	87.0	42.0
Corn ".....	88.4	89.0	.....	75.6	40.0	95.7	73.1

Digestion by Swine.

Barley.....	80.1	80.3	5.4	81.4	48.7	86.6	57.0
Corn (unground).....	89.7	91.3	.....	89.9	48.7	93.9	77.6
Corn (finely ground).....	89.5	91.2	.....	86.1	29.4	94.2	81.7
Corn and cob meal.....	75.6	76.7	.....	75.7	28.5	83.6	82.0
Wheat (unground).....	72.0	.....	44.0	70.0	30.0	74.0	60.0
Wheat (cracked).....	82.0	.....	50.0	80.0	60.0	83.0	70.0
" bran.....	65.8	.....	.....	75.1	33.0	65.5	71.8
Linseed meal.....	77.5	.....	10.0	86.0	12.0	85.0	80.0

WOLFF'S FEEDING STANDARDS.*Per day per 1000 lbs. live weight.*

Kind of animal	Total dry matter	Digestible organic matter			Nutritive ratio 1:
		Protein	Carbo-hydrates	Fat	
1. Oxen	Lbs.	Lbs.	Lbs.	Lbs.	
At rest.....	18	0.7	8.0	0.1	11.8
Light work.....	22	1.4	10.0	0.3	7.7
Moderate work.....	25	2.0	11.5	0.5	6.5
Severe work.....	28	2.8	13.0	0.8	5.3
2. Fattening bovines					
First period.....	30	2.5	15.0	0.5	6.5
Second period.....	30	3.0	14.5	0.7	5.4
Third period.....	26	2.7	15.0	0.7	6.2
3. Milch cows					
Daily milk yield 11 lbs.	25	1.6	10.0	0.3	6.7
Daily milk yield 22 lbs.	29	2.5	13.0	0.5	5.7
4. Sheep					
Coarse wool.....	20	1.2	10.5	0.2	9.1
Fine wool.....	23	1.5	12.0	0.3	8.5
Ewes, suckling lambs.....	25	2.9	15.0	0.5	5.6
Fattening sheep					
First period.....	30	3.0	15.0	0.5	5.4
Second period.....	28	3.5	14.5	0.6	4.5
5. Horses					
Light work.....	20	1.5	9.5	0.4	7.0
Heavy work.....	26	2.5	13.3	0.8	6.0
6. Brood sows.....	22	2.5	15.5	0.4	6.6
7. Fattening swine					
First period.....	36	4.5	25.0	0.7	5.9
Second period.....	32	4.0	24.0	0.5	6.3
Third period.....	25	2.7	18.0	0.4	7.0

WOLFF'S FEEDING STANDARDS (Continued).

Kind of animal Age in months	Live weight per head	Total dry matter	Digestible organic matter			Nutritive ratio 1:
			Protein	Carbo- hydrates	Fat	
Growing cattle	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
DAIRY BREEDS.						
2-3.....	150	23	4.0	13.0	2.0	4.5
3-6.....	300	24	3.0	12.8	1.0	5.1
6-12.....	500	27	2.0	12.5	0.5	6.8
12-18.....	700	26	1.8	12.5	0.4	7.5
18-24.....	900	26	1.5	12.0	0.3	8.5
BEEF BREEDS.						
2-3.....	165	23	4.2	13.0	2.0	4.2
3-6.....	330	24	3.5	12.8	1.5	4.7
6-12.....	550	25	2.5	13.2	0.7	6.0
12-18.....	750	24	2.0	12.5	0.5	6.8
18-24.....	935	24	1.8	12.0	0.4	7.2
Growing sheep						
WOOL BREEDS.						
4-6.....	60	25	3.4	15.4	0.7	5.0
6-8.....	75	25	2.8	13.8	0.6	5.4
8-11.....	85	23	2.1	11.5	0.5	6.0
11-15.....	90	22	1.8	11.2	0.4	7.0
15-20.....	100	22	1.5	10.8	0.3	7.7
MUTTON BREEDS.						
4-6.....	65	26	4.4	15.5	0.9	4.0
6-8.....	85	26	3.5	15.0	0.7	4.8
8-11.....	100	24	3.0	14.3	0.5	5.2
11-15.....	120	23	2.2	12.6	0.5	6.3
15-20.....	150	22	2.0	12.0	0.4	6.5
Growing swine.						
BREEDING STOCK.						
2-3.....	45	44	7.6	28.0	1.0	4.0
3-5.....	100	35	5.0	23.1	0.8	5.0
5-6.....	120	32	3.7	21.3	0.4	6.0
6-8.....	175	28	2.8	18.7	0.3	7.30
8-12.....	260	25	2.1	15.3	0.2	7.5
Growing Fattening Animals.						
2-3.....	45	44	7.6	28.0	1.0	4.0
3-5.....	110	35	5.0	23.1	0.8	5.0
5-6.....	150	33	4.3	22.3	0.6	5.5
6-8.....	200	30	3.6	20.5	0.4	6.0
8-12.....	275	26	3.0	18.3	0.3	6.4

PRODUCTION VALUES PER 100 POUNDS.

A table giving the productive value of feeds for fattening purposes. Computed according to Kellner.

Feeding Stuff	Total Dry Matter	Total Crude Fiber	Digestible			Production Value Thermo
			Protein	Carbo- hydrates	Fat	
Green Fodder and Silage:	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
Alfalfa.....	28.2	7.4	2.50	11.20	0.41	10.80
Clover—Red.....	29.2	8.1	2.21	14.82	0.69	14.52
Corn Fodder.....	20.7	5.0	0.41	12.08	0.37	11.02
“ Silage.....	25.6	5.8	1.21	14.57	0.88	14.26
Hungarian Grass.....	28.9	9.2	1.33	15.63	0.36	13.14
Rye.....	23.4	11.6	1.44	14.11	0.44	10.31
Timothy.....	38.4	11.8	1.04	21.22	0.64	17.80
Hav and Dry Coarse Fodders:						
Alfalfa Hay.....	91.6	25.0	6.93	37.33	1.38	34.41
Clover Hay—Red.....	84.7	24.8	5.41	38.15	1.81	34.73
Corn Fodder (field cured).....	57.8	14.3	2.13	32.34	1.15	30.53
“ Stover.....	59.5	19.7	1.80	33.16	0.57	26.53
Cow Pea Hay.....	89.3	20.1	8.57	38.40	1.51	42.76
Hungarian Hay.....	92.3	27.7	3.00	51.67	1.34	44.03
Oat Hay.....	84.0	27.2	2.59	33.35	1.67	36.97
Soy Bean Hay.....	88.7	22.3	7.68	38.72	1.54	38.65
Timothy Hay.....	86.8	29.6	2.05	43.72	1.43	33.56
Straws:						
Oat.....	90.8	37.0	1.09	38.64	0.76	21.21
Rye.....	92.9	38.9	0.63	40.58	0.38	20.87
Wheat.....	90.4	38.1	0.37	36.30	0.40	16.56
Roots, etc.:						
Carrots.....	11.4	1.3	0.37	7.83	0.22	7.82
Mangel-wurzels.....	9.1	0.8	0.14	5.65	0.11	4.62
Potatoes.....	21.1	0.6	0.45	16.43	.....	18.05
Turnips.....	9.5	1.2	0.22	6.46	0.11	5.74
Grains:						
Barley.....	89.1	2.7	8.37	64.83	1.60	80.75
Corn.....	89.1	2.1	6.79	66.12	4.97	88.84
Corn and Cob Meal.....	84.9	6.6	4.53	60.06	2.94	72.05
Oat.....	89.0	9.5	8.36	48.34	4.18	66.27
Rye.....	88.4	1.7	8.12	69.73	1.36	81.72
Wheat.....	89.5	1.8	8.90	69.21	1.68	82.63
By Products:						
Brewers' Grains—wet.....	24.3	3.8	3.81	9.37	1.38	14.82
Cottonseed meal.....	91.8	5.6	35.15	16.52	12.58	84.20
Gluten Feed—dry.....	91.9	6.4	19.95	54.22	5.35	79.32
“ Meal, Buffalo.....	91.8	6.1	21.56	43.02	11.87	85.46
Linseed meal:						
Old Process.....	90.8	8.9	27.53	32.81	7.06	78.92
New “.....	90.1	8.8	29.26	38.72	2.90	74.67
Malt Sprouts.....	89.8	10.7	12.36	43.50	1.16	46.33
Rye Bran.....	88.2	3.3	11.35	52.40	1.79	56.65
Wheat Bran.....	88.5	9.0	10.21	41.23	2.87	48.23

POUNDS OF PLANT FOOD PER ACRE REMOVED BY AVERAGE CROPS.

	Weight of Crop		Total pure ash	Nitrogen	Sulphur trioxide	Potash	Soda	Lime	Magnesia	Phosphoric acid	Chlorin	Silica
	At harvest	Dry										
Wheat grain 30 bu.....	1,800	1,530	30	34	6.4	9.3	0.6	1.0	3.6	14.2	0.1	0.6
" straw.....	3,158	2,653	142	16	9.3	19.5	2.0	8.2	3.5	6.9	2.4	96.3
Total crop.....	4,958	4,183	172	50	15.7	28.8	2.6	9.2	7.1	21.1	2.5	96.9
Barley grain, 40 bu.....	2,080	1,747	46	35	6.6	9.8	1.1	1.2	4.0	16.0	0.5	11.8
" straw.....	2,447	2,080	111	14	7.7	25.9	3.9	8.0	2.9	4.7	3.6	56.8
Total crop.....	4,527	3,827	157	49	14.3	35.7	5.0	9.2	6.9	20.7	4.1	68.6
Oat grain, 45 bu	1,890	1,625	51	34	7.5	9.1	0.8	1.8	3.6	13.0	0.5	19.9
" straw.....	2,835	2,353	140	18	12.2	37.0	4.6	9.8	5.1	6.4	6.1	65.4
Total crop.....	4,725	3,978	191	52	19.7	46.1	5.4	11.6	8.7	19.4	6.6	85.3
Corn grain, 30 bu.....	1,680	1,500	22	28	6.4	6.5	0.2	0.5	3.4	10.0	0.2	0.5
" stalks, etc.....	2,208	1,877	99	15	5.6	29.8	1.2	10.7	5.6	8.0	1.4	28.5
Total crop.....	3,888	3,377	121	43	12	36.3	1.4	11.2	9.0	18.0	1.6	29.0
Meadow hay.....	3,360	2,822	203	49	11.3	50.9	9.2	32.1	14.4	12.3	14.6	56.9
Red Clover hay.....	4,480	3,763	258	98	15.4	83.4	5.1	90.1	28.2	24.9	9.8	7.0
Alfalfa hay .....	.....	9,000	678	197	64.8	213.2	16.4	212.9	53.0	39.9	71.3	13.4

POUNDS OF PLANT FOOD PER ACRE REMOVED BY AVERAGE CROPS. — (Continued).

	Weight of Crop		Total pure ash	Nitrogen	Sulphur trioxide	Potash	Soda	Lime	Magnesia	Phosphoric acid	Chlorin	Silica
	At harvest	Dry										
Beans grain, 30 bu.....	1,920	1,613	58	78	9.4	24.3	0.6	2.9	4.2	22.8	1.1	0.4
" straw.....	2,240	1,848	99	29	4.9	42.8	1.7	26.3	5.7	6.3	4.3	6.9
Total crop.....	4,160	3,461	157	107	14.3	67.1	2.3	29.2	9.9	29.1	5.4	7.3
Turnip, roots.....	38,080	3,126	218	61	57.8	108.6	17.0	25.5	5.7	22.4	10.9	2.6
" leaf.....	11,424	1,531	146	49	34.4	40.2	7.5	48.5	3.8	10.7	11.2	5.1
Total crop.....	49,504	4,657	364	110	92.2	148.8	24.5	74.0	9.5	33.1	22.1	7.7
Sugar beet, root.....	24,000	4,320	165	53	9.5	87.9	14.8	10.0	13.0	20.2	8.0	3.8
" leaf.....	8,400	1,848	275	34	20.0	72.2	37.8	55.5	31.2	13.1	23.3	28.0
Total crop.....	32,400	6,168	440	87	29.5	160.1	52.6	65.5	44.2	33.3	31.3	31.8
Mangel, root.....	49,280	5,914	426	98	4.9	222.8	69.4	15.9	18.3	36.4	42.5	8.7
" leaf.....	18,233	1,654	254	51	9.1	77.9	49.3	27.0	24.2	16.5	40.6	9.2
Total crop.....	67,513	7,568	680	149	14.0	300.7	118.7	42.9	42.5	52.9	83.1	17.9
Potatoes, tubers.....	13,440	3,360	127	46	2.7	76.5	3.8	3.4	6.3	21.5	4.4	2.6
Beech, wood.....		2,822	26	10	.....	4.2	0.8	12.9	3.4	1.5	.....	2.2
" leaf litter.....		2,975	166	39		8.8	1.6	73.1	10.9	9.3		53.9
Total produce.....		5,797	192	49		13.0	2.4	86.0	14.3	10.8		56.1

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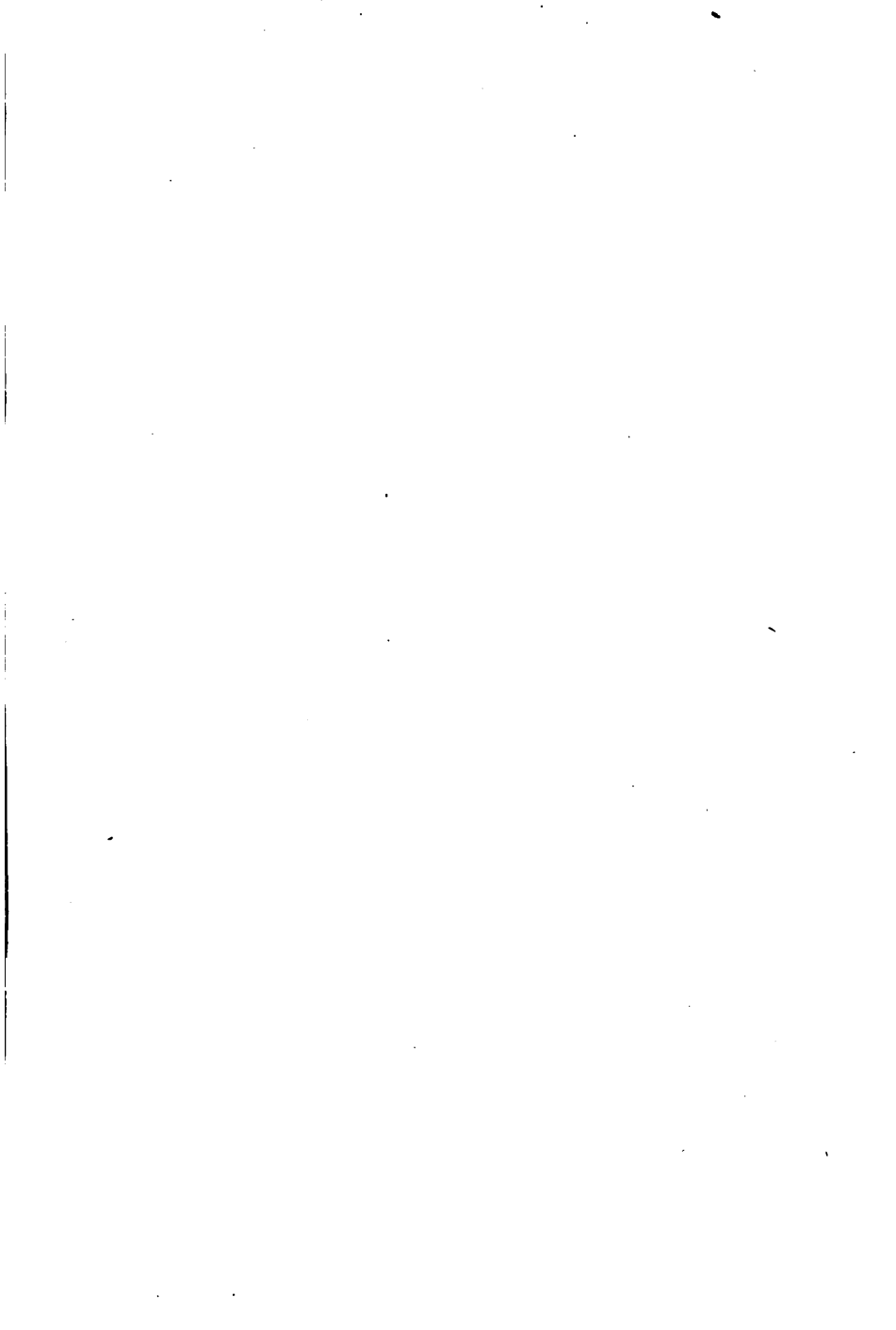
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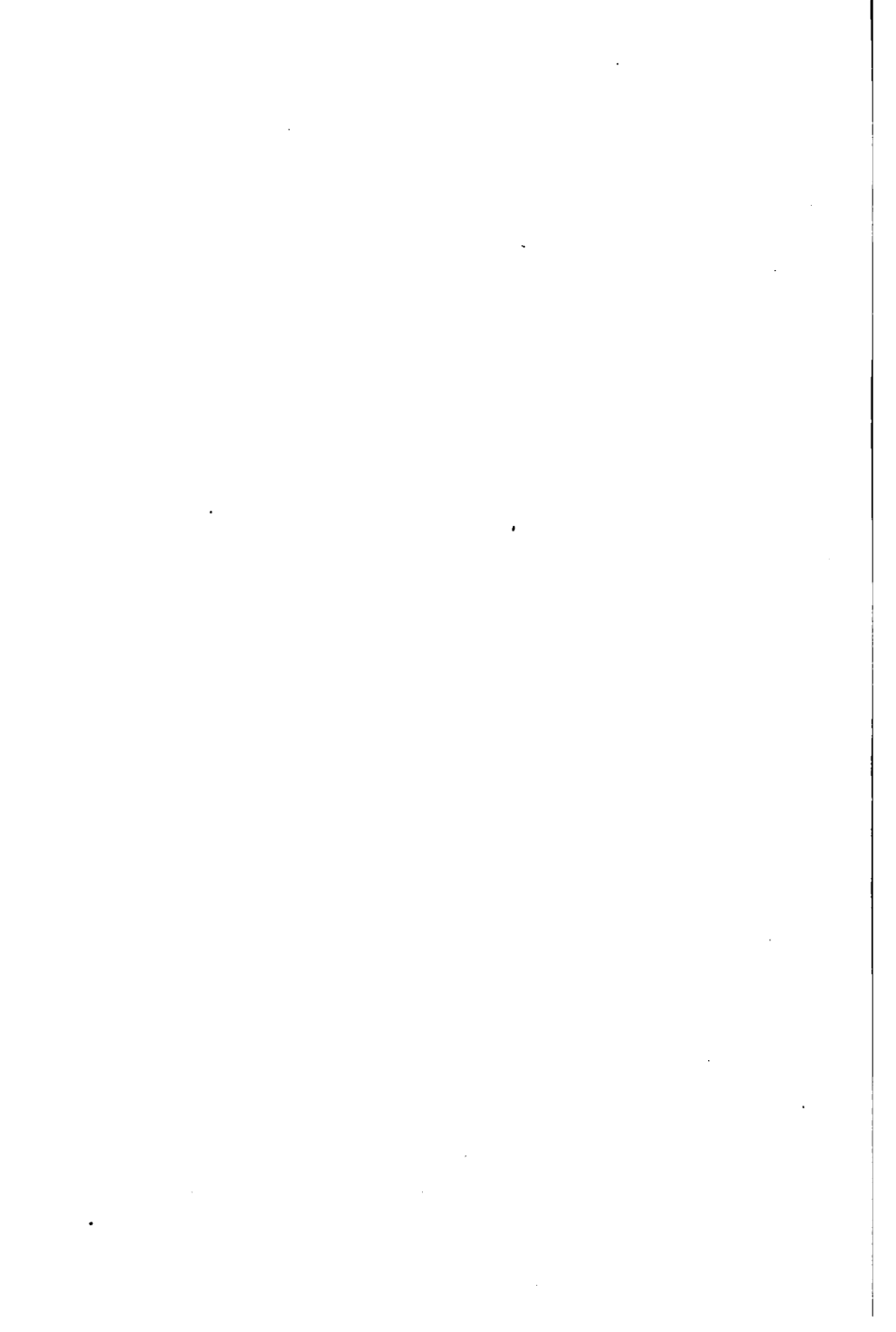
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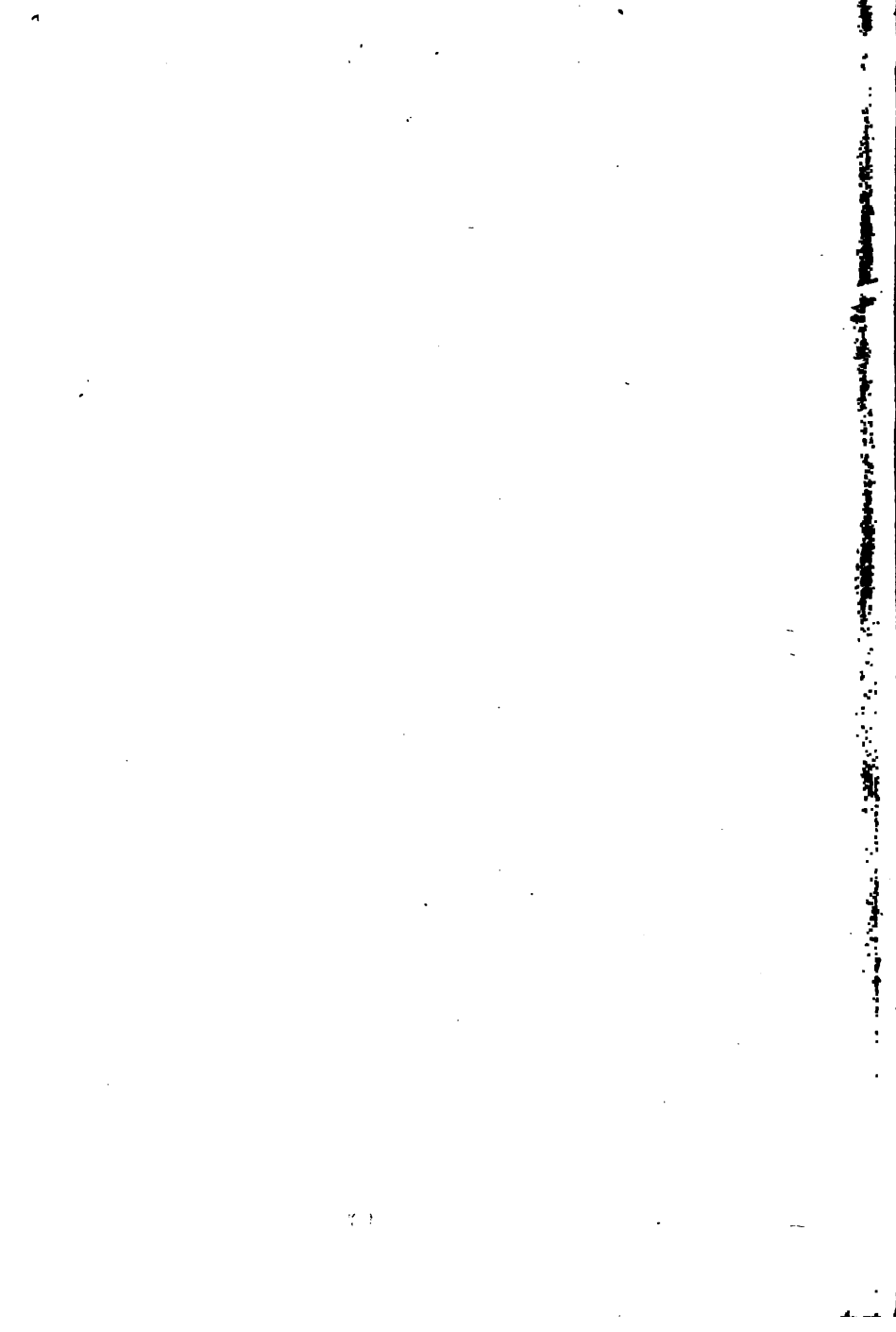












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